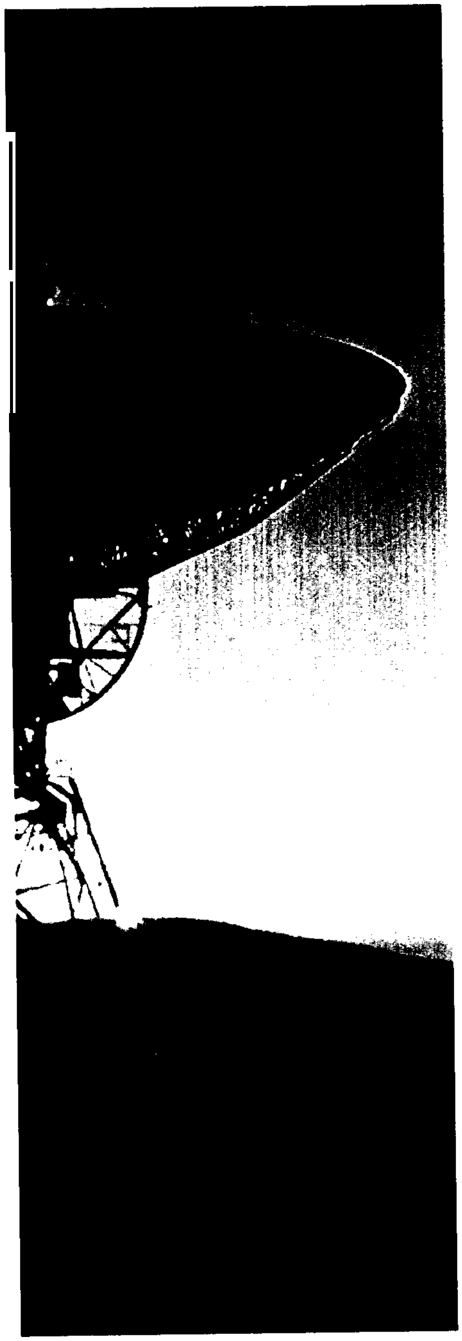
JPL D-14737

Goldstone-Apple Valley
Radio Telescope System

Theory of Operation



learning Module

October 1997

Jet Propulsion Laboratory
California Institute of Technology

Goldstone-Apple Valley Radio Telescope System

Theory of Operation

Learning Module

Preparation and Photography by

George R. Stephan

Advanced Mission Operations Section

October 1997

Jet Propulsion laboratory
California Institute of Technology

JPL D-14737

DOCUMENT LOG

Goldstone-Apple Valley Radio Telescope System Learning Module

Document Identifier	Date	Description
D-14737	10/1/97	Presents the GAVRT System theory of operations to internet learners

PREFACE

In a collaborative effort, the Apple Valley (California) Science and Technology Center (AVSTC), the Apple Valley Unified School District, the Jet Propulsion Laboratory, and NASA, have converted a 34-meter tracking antenna at NASA's Deep Space Network's (DSN) Goldstone Complex into a teaching and scientific instrument available to classrooms throughout the United States via the internet.

The Goldstone-Apple Valley Radio Telescope (GAVRT) is located in a remote area of the Mojave Desert, 40 miles north of Barstow, California. The antenna, DSS-12 (Deep Space Station-12), is a 34-meter diameter dish, 11 times the diameter of the microwave dishes used for satellite television reception. DSS-12 has been used by NASA to communicate with robotic space probes for more than thirty years. In 1994, when NASA decided to decommission DSS-12 from the DSN, a group of professional scientists, educators, engineers, and several community volunteers envisioned a new use for this antenna, and began work on what has become the GAVRT project.

The GAVRT project is jointly managed by the AVSTC and the DSN Office of Telecommunications and Mission Operations Directorate (TMOD), at the California Institute of Technology's, Jet Propulsion Laboratory.

This learning module describes how the GAVRT system works, and is presented as part of the learning required to operate the telescope. Students and teachers in classrooms will be able to register with the center's internet site and operate the telescope from their own classrooms, using personal computers, under the oversight of AVSTC GAVRT system operators.

ACKNOWLEDGMENTS

The following people made significant contributions in time and expertise toward the development of this learning module. Without their efforts this module could not have been developed.

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Goldstone Historical Research	George F. Stephan, author's father

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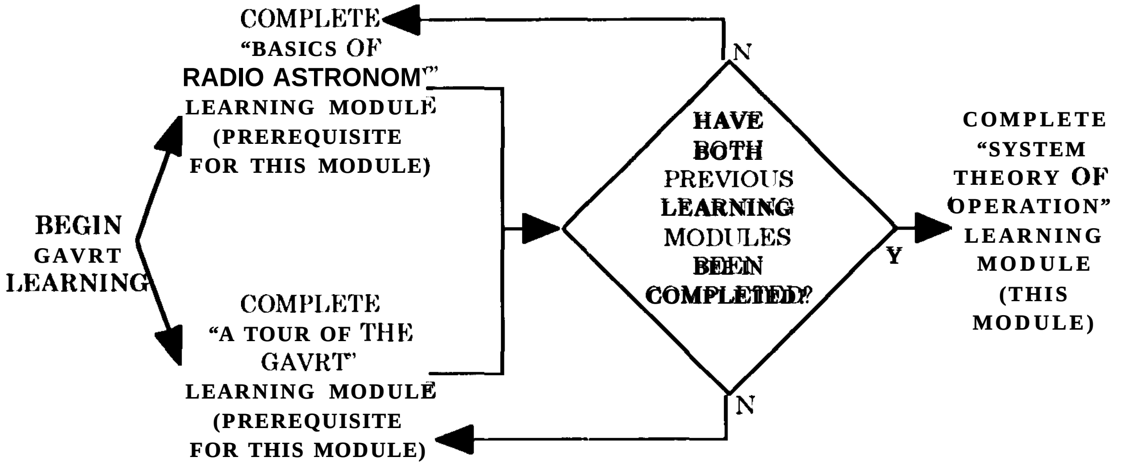
Learning Module Overview

The prerequisites for this learning module are the completion of the "Basics of Radio Astronomy" and "A Tour of the GAVRT Antenna" learning modules.

GAVRT DISTANCE LEARNING MODULE SEQUENCE



If you have not already completed these learning modules you should do so now because this module builds on what was learned in the previous module in the sequence.

The "Basics of Radio Astronomy" learning module maybe downloaded without charge from URL:

http: //www.jpl.nasa. gov/radioastronomy/

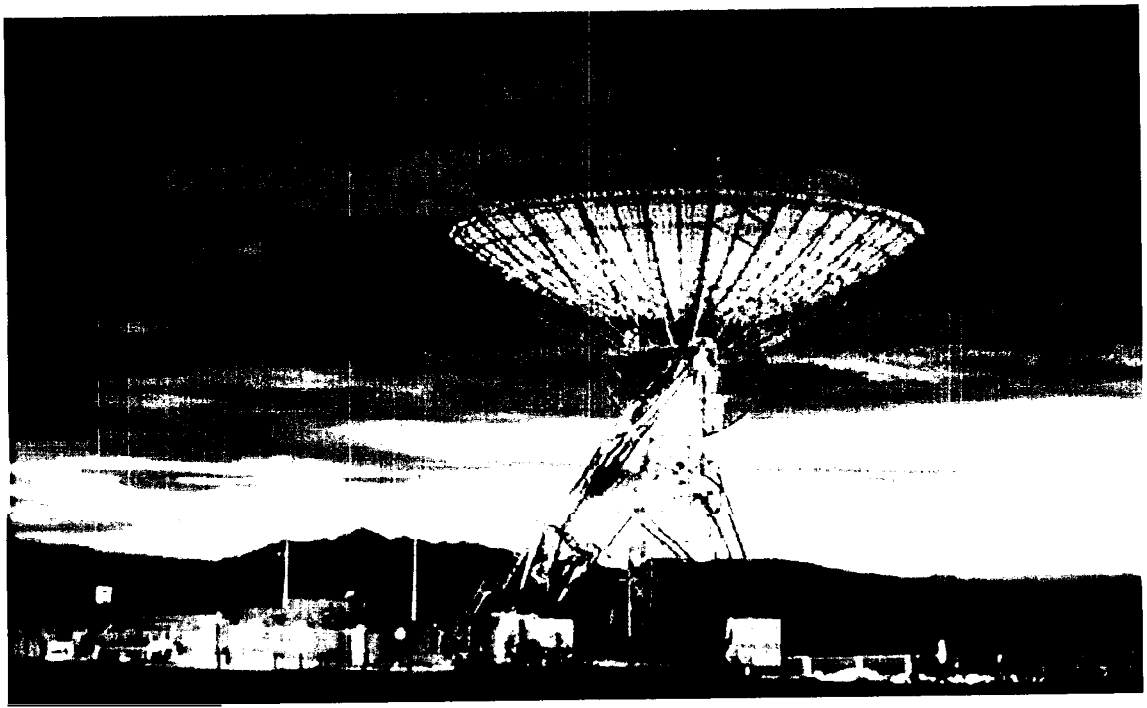
The "Basics of Radio Astronomy" module describes how electromagnetic signals are created naturally in outer space, and how they are propagated through space to the GAVRT antenna. This learning module picks up where the "Basics of Radio Astronomy" leaves off, with the arrival of electromagnetic signals at the antenna, and describes how they are processed, how relevant signal and monitor data are delivered to client schools, and how client schools machines control the GAVRT system. The learning strategy used in this module presents each learning objective's associated material in a text format, supports that text with graphics, and reinforces the learning by way of short quizzes.

A comp anion module, "A Tour of the GAVRT Antenna", provides a still-frame tour of the antenna, and it imp arts a feel for the size the antenna. The "A Tour of the GAVRT Antenna" learning module will be available online from the AVSTC web site by November 1, 1997. Check on all GAVRT learning module availability at URL:

http://www.avstc.org/

The Purpose of This Learning Module ....

The purpose of this learning module is to enable learners to describe how the Goldstone-Apple Valley Radio Telescope (GAVRT) system functions in support of Apple Valley Science and Technology Center's (AVSTC) client schools' radio astronomy activities.



DAWN AT THE GAVRT ANTENNA AS A PACIFIC STORM APPROACHES

This module was derived from a lecture-guided tour course presented to the GAVRT operators at the AVSTC in the spring of 1997. The module presents an element of learning in text, provides graphical support of the element, and then via quizzes, asks brief fill-in-the-blank type of questions. These quizzes provide learning reinforcement and a sense of accomplishment to the learners.

The photographs in this module will provide a good idea of the size and appearance of the GAVRT antenna, since most of you will not have the opportunity to see or touch the instrument personally. For more detailed information about the photography in this module, see “Appendix D: About this Module”.

The Adobe Acrobat .pdf file system was selected as the primary wrapper for delivery of this module because of its cross-platform capabilities, and its ability to print virtually what it displays on a screen. This module may be used in two ways: 1) download it onto your hard drive, and then use it as an on-screen resource; and 2) download it onto your hard drive, print, and then use it as a paper document. Maximum Acrobat presentation resolution may be obtained by “zooming” in on the onscreen image using Adobe Acrobat Reader™.

Although all photographs are presented in color, they will be displayed/ printed in black and white, unless the learner has a color monitor and/or printer. To view Adobe Acrobat .pdf files, the Adobe Acrobat Reader™ must be frost downloaded from Adobe’s web site and be installed on your computer. The Acrobat Reader™ is available for downloading without charge at URL

http: //www.adobe.com/prodindex/acrob at/readstep.html

This module is also available as a Microsoft Word file that may downloaded from the AVSTC web site. Maximum Microsoft Word onscreen presentation resolution may be obtained by setting the onscreen image display size to “200%”.

George R. Stephan
Training Engineer
October 1, 1997
Jet Propulsion Laboratory

INTRODUCTION TO THE GAVRT SYSTEM

Learning Objectives for this Section

Completion of this section will enable learners to:

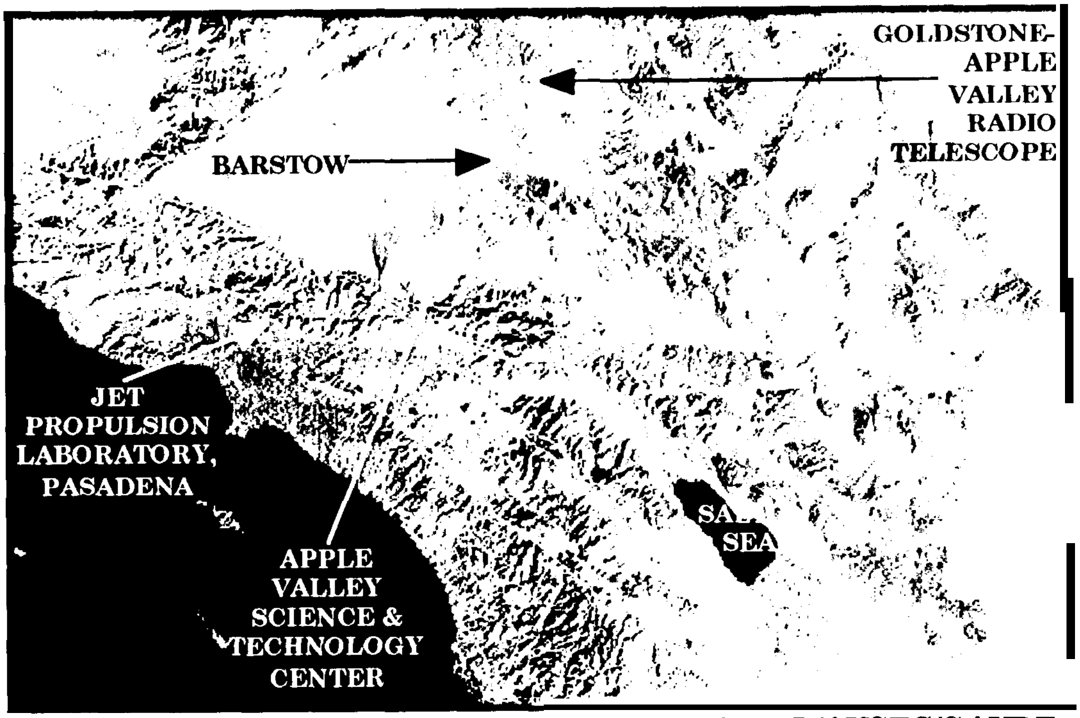
- Describe the geographical location of the Apple Valley Science & Technology Center
- Describe the geographical location of JPL (Jet Propulsion Laboratory)
- Describe the geographical location of the GDSCC (Goldstone Deep Space Communications Complex)
- Describe the distance between the locations of JPL and the AVSTC
- Describe the distance between the locations of the AVSTC and GDSCC
- Describe the distance between the locations of GAVRT antenna and SPC-10 at GDSCC
- Describe the geography of the Goldstone area
- Describe the climate of the Goldstone area
- Describe the functional relationship between NASA and JPL
- Describe what each DSN (Deep Space Network) complex consists of
- Identify the type of radio telescope that the GAVRT is
- Describe the general function of the GAVRT antenna
- Describe the general function of the LNA's (Low Noise Amplifiers)
- Describe the general function of the downconverter.
- Describe the purpose of the surveillance television camera
- Describe the purpose of the meteorological sensors
- Describe the geocentric coordinates of the GAVRT antenna

- Describe why the GAVRT antenna sets on top of raising blocks
- Describe what the stationary supporting structure supports
- Describe the orientation of the polar shaft
- Describe the equipment bolted to each skid
- Describe the reason each axis has two motor-gear box sets
- Describe why the commands to each drive motor on the same axis are different
- Describe the maximum rotational rate for either axis of the antenna
- Describe the size relationship between the drive mechanisms of the two axis
- Describe in general how signals are collected and focused in the RF feeds in the cone
- Describe the function of the power meter
- Describe the function of the GAVRT Sun Sparc-20 workstation
- Describe the source of GAVRT's frequency and timing signals
- Describe the two sources of power for GAVRT devices at Goldstone
- Describe what the GAVRT workstation does with the AVSTC workstation commands
- Describe the function of the end user's PC during GAVRT operations

GAVRT Geography

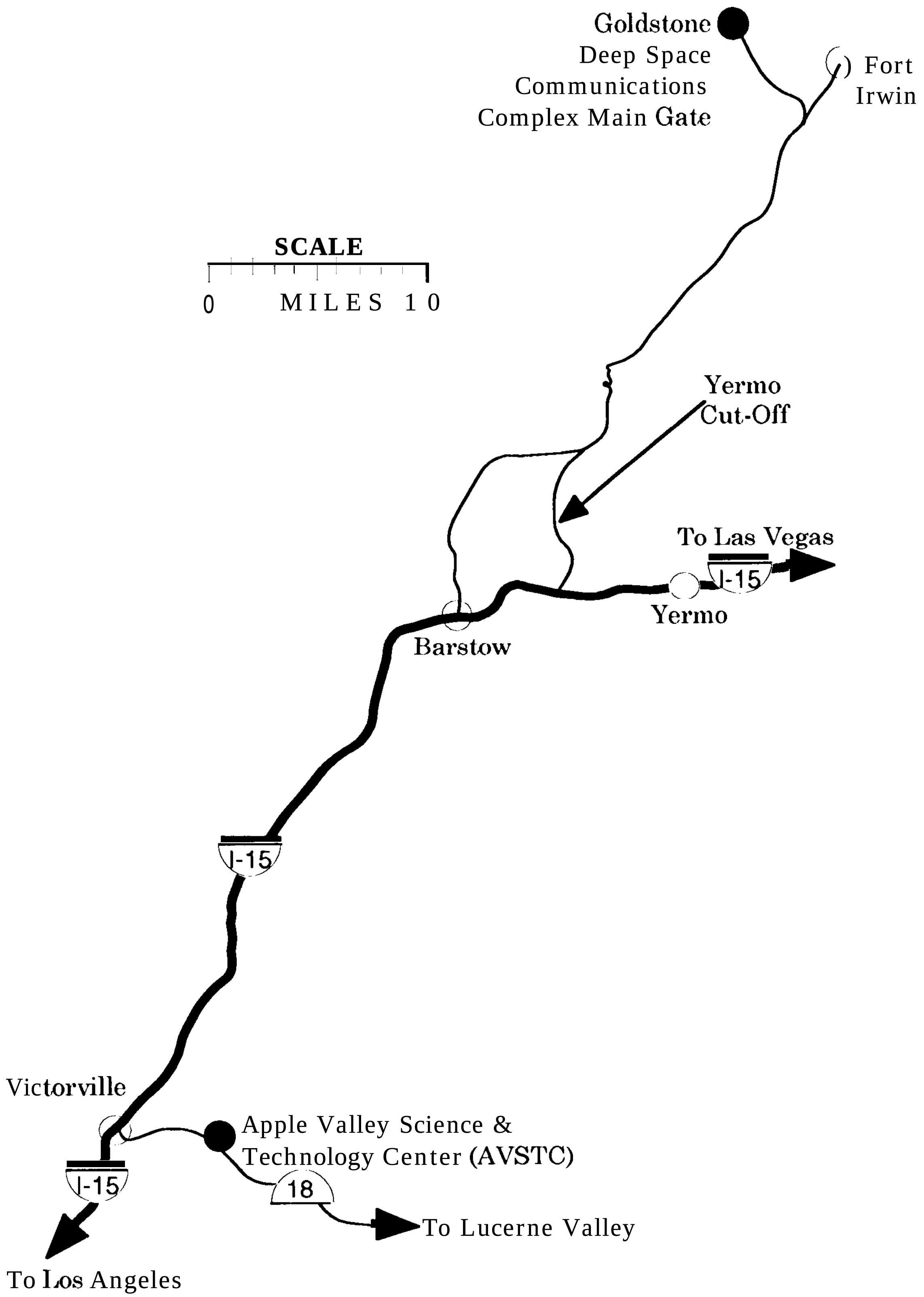
The California Institute of Technology's (Cal tech) Jet Propulsion Laboratory (JPL) is located in Pasadena, California. An hour and half away via Interstate- 15, is the Apple Valley Science & Technology Center (AVSTC) located in Apple Valley, California. An hour and half north of the AVSTC, through Barstow, California, is the GDSCC (Goldstone Deep Space

Communications Complex), including the GAVRT (Goldstone-Apple Valley Radio Telescope). The AVSTC and the GAVRT antenna are both located on the Mojave Desert, sometimes referred to locally as the High Desert, and are on the North American tectonic plate.



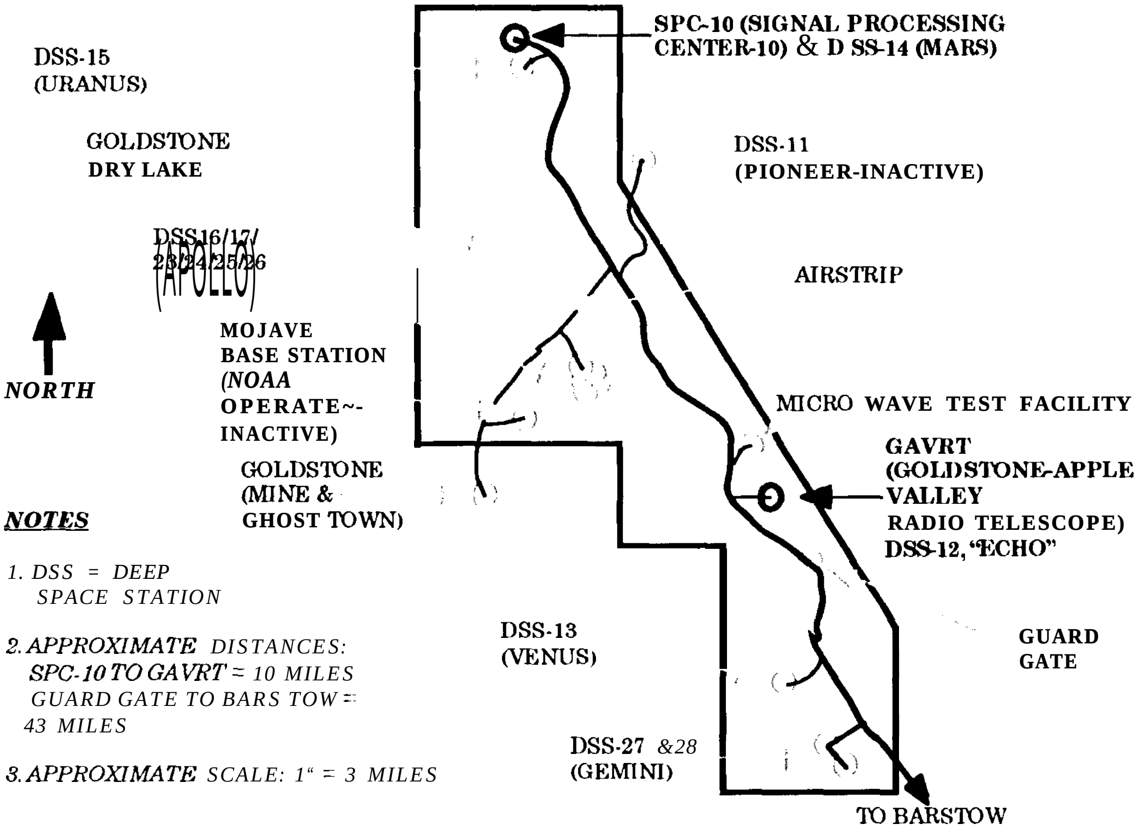
SOUTHERN CALIFORNIA SATELLITE VIEW: JPL/AVSTC/GAVRT
(Irregular white lines = earthquake faults)

Focusing on the relative locations of the AVSTC and the GDSCC (Goldstone Deep Space Communications Complex) on the following map, the distances involved become apparent. Driving from the AVSTC to the GAVRT antenna at Goldstone takes about 90 minutes.



APPLE VALLEY-GOLDSTONE HIGHWAY MAP

The following map is of the Goldstone Deep Space Communications Complex, located approximately 40 miles north of Barstow. Notice that the distance between SPC- 10 (Signal Processing Center-10) and the GAVRT antenna is approximately 10 miles. SPC- 10, from which all Goldstone operations are overseen except for the GAVRT antenna, is staffed 24 hours a day. Excluding occasional engineering and maintenance activities, operations at the GAVRT antenna site (DSS- 12 or Echo) at Goldstone have been automated/remote controlled and require no operations staff at the antenna location.



GOLDSTONE DEEP SPACE COMMUNICATIONS COMPLEX MAP

The Goldstone complex also contains several playas or dry lakes. Almost always Goldstone dry lake is as&y as the proverbial bone , as seen in the next photograph. However, occasionally, during a heavy winter storm, enough water will run off of the surrounding hills to fill the lake to a depth of several inches, and may last several weeks until the water evaporates. During these periods Goldstone dry lake becomes populated with tiny brine shrimp. When Goldstone was first constructed in the early 1960s, this dry lake was used as a runway for aircraft. Today Goldstone has a paved airstrip adjacent to the dry lake (see previous map, Goldstone Deep Space Communications Complex Map).

GOLDSTONE DRY LAKE

QUIZ

1, Driving from the AVSTC to the GAVRT antenna at Goldstone takes about ________ minutes. **Answer: 90.**

2. ...the distance between SPC- 10 (Signal Processing Center-10) and the GAVRT antenna is approximately ____________ miles.
Answer: 10.

System Overview

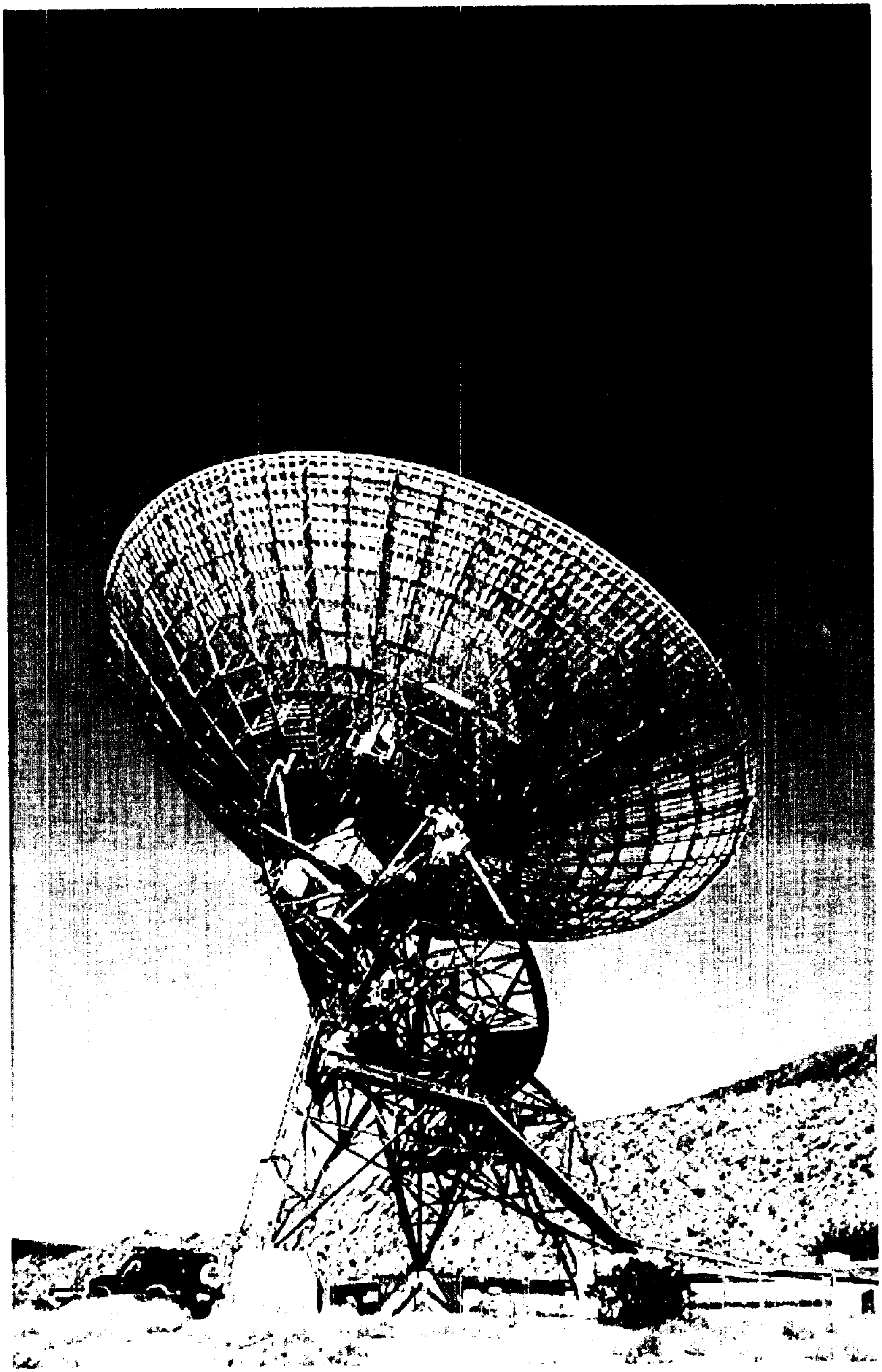
The California Institute of Technology's (Caltech) Jet Propulsion Laboratory (JPL) operates and maintains a world-wide network of deep space tracking stations known as the Deep Space Network (DSN) for the National Aeronautics and Space Administration (NASA). The DSN is geographically arranged into three Deep Space Communications Complexes (DSCC) of tracking stations 120 degrees of latitude apart in Canberra, Australia, Madrid, Spain, and Goldstone, California. Each complex consists of several deep space stations (DSS) with steerable antenna aperture diameters from 9 to 70 meters. At the Goldstone Deep Space Communications Complex (GDSCC) located in California's Mojave desert is Deep Space Station-12

(DSS-12, also known as the Echo Site). 1) SS-12 was a steerable, 34 meter diameter, hour-angle/declination mount, deep space tracking antenna. DSS-12 originally became operational in 1964.

Check out this URL for more detailed information about the DSN (Deep Space Network):

http: //deepspace.jpl. nasa. gov/dsn/index.html

In 1997 DSS- 12 was converted into a dedicated radio telescope of the *total power radiometer* type, re-named the Goldstone-Apple Valley Radio Telescope (GAVRT), and operations of the telescope were turned over to the Apple Valley Science and Technology Center (AVSTC). The AVSTC makes this scientific instrument available for use by K-12 schools via the internet. The AVSTC will oversee day-to-day operations of the GAVRT, and GDSCC personnel will maintain the operability of the system.



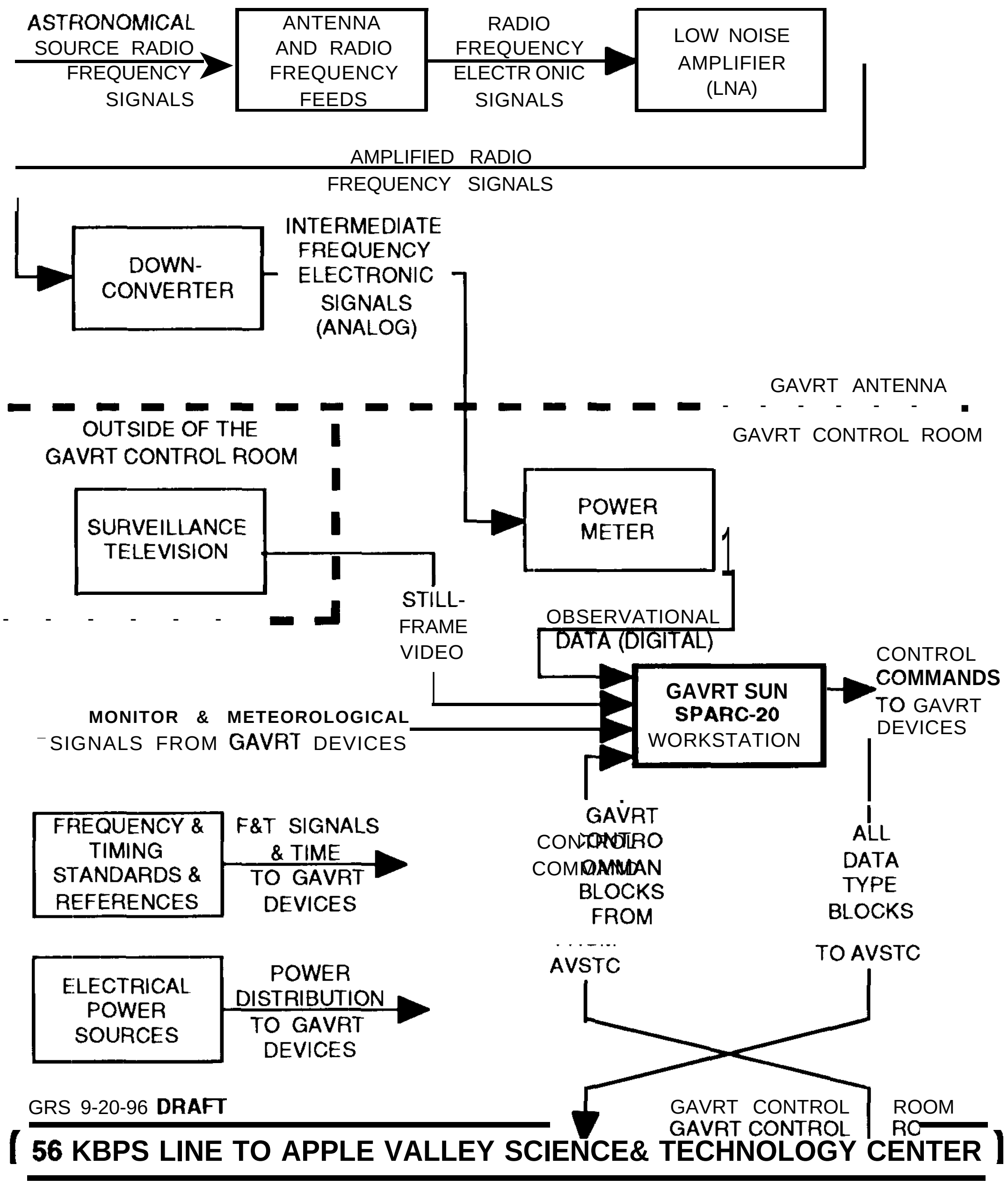
GAVRT ANTENNA AT NORTH LIMIT

In conjunction with the California State Polytechnic University --Pomona (Calpoly--Pomona), AVSTC personnel have prepared science curricula appropriate to the use of the GAVRT by teachers and students in the integration of radio telescope observations with school curricula. Within the structure of this curricula are opportunities for students to conceptualize, design, execute, collect the data from, and analyze GAVRT observations via the internet. Students may perform actual scientific observations when operating the telescope in the conduct of their experiments, as well as have access to data collected by other GAVRT experimenters. All GAVRT internet operations by client schools are conducted under the oversight of GAVRT personnel at the AVSTC (Apple Valley Science and Technology Center) in Apple Valley.

To introduce the overall functionality of the GAVRT ***total power radiometer,*** this overview section is based on the greatly simplified signal/data flow diagrams (Parts 1 &2) of the GAVRT system. However, all of the major functions and signal/data types of the system are included on these diagrams.

SIMPLIFIED GAVRT SYSTEM SIGNAL/DATA FLOW DIAGRAM

PART 1 —GAVRT ANTENNA & CONTROL ROOM AT GOLDSTONE



QUIZ

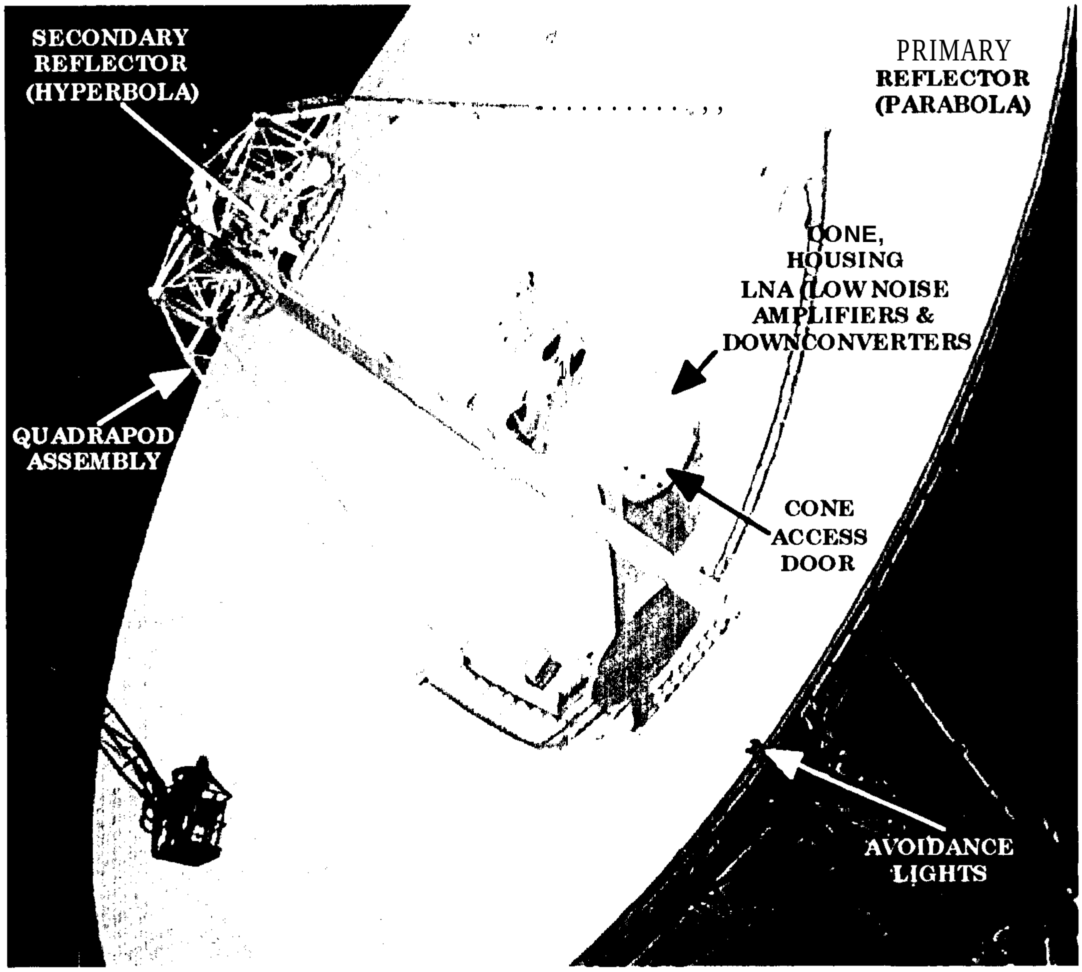
1. In 1997 DSS-12 was converted into a dedicated radio telescope of the ______________________ type . . . . **Answer: Total power radiometer.**

2. All GAVRT internet operations by client schools are conducted under the oversight of GAVRT personnel at the ______________________________ in Apple Valley.

Answer: AVSTC (Apple Valley science and Technology Center),

At the GAVRT Antenna

The steerable 34 meter diameter GAVRT antenna and RF (radio frequency) feeds collect extremely weak astronomical source RF signals from a very narrow sector of deep space, and focuses them at the input to the first stage amplifier, the Low Noise Amplifier (LNA). The LNA's purpose is to increase the power of the incoming signal as much as possible (100,000-700,000 times) without adding appreciable noise (static). The signal is then translated into an amplified, proportionally lower, frequency signal called the Intermediate Frequency (IF) by the downconverter.



GAVRT ANTENNA REFLECTORS, CONE, AND QUADRAPOD

The amplified IF signal is now strong enough to be sent via coaxial cables to the Power Meter in GAVRT's Control Room without being lost in the noise of the system.

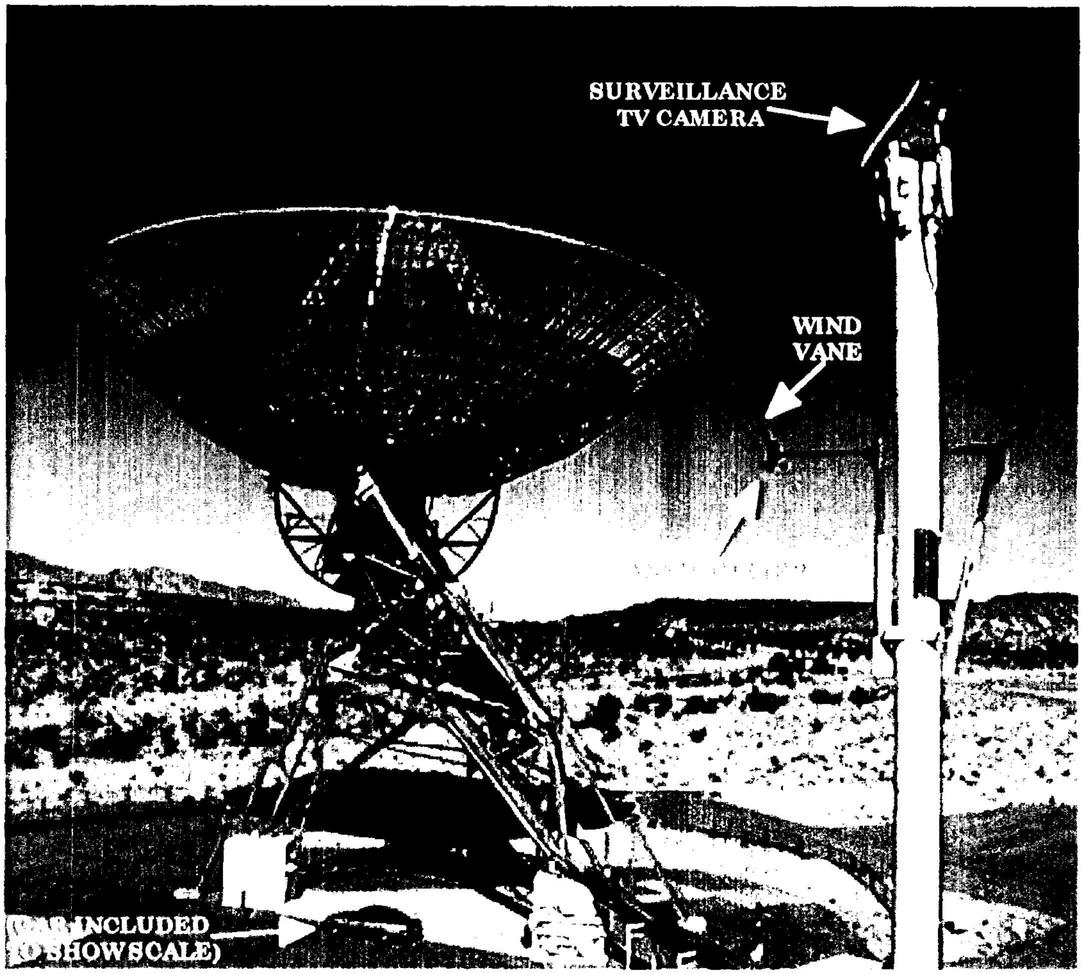
QUIZ

1. The LNA's purpose is to increase the power of the incoming signal as much as possible (100,000-700,000 times) without adding __________
   Answer: Appreciable noise , or static.

2. The signal is then down-converted into an amplified proportionally lower frequency signal called the ____________________
   Answer: Intermediate Frequency , or IF.

Outside of the GAVRT Control Room

A surveillance TV camera is mounted on top of a mast just outside of the control room. The purpose of this camera is to provide remotely-located GAVRT operators a clear view of the GAVRT antenna and its immediate environment. This camera sends still-frame video to the GAVRT Sun Sparc-20 Workstation in the control room.

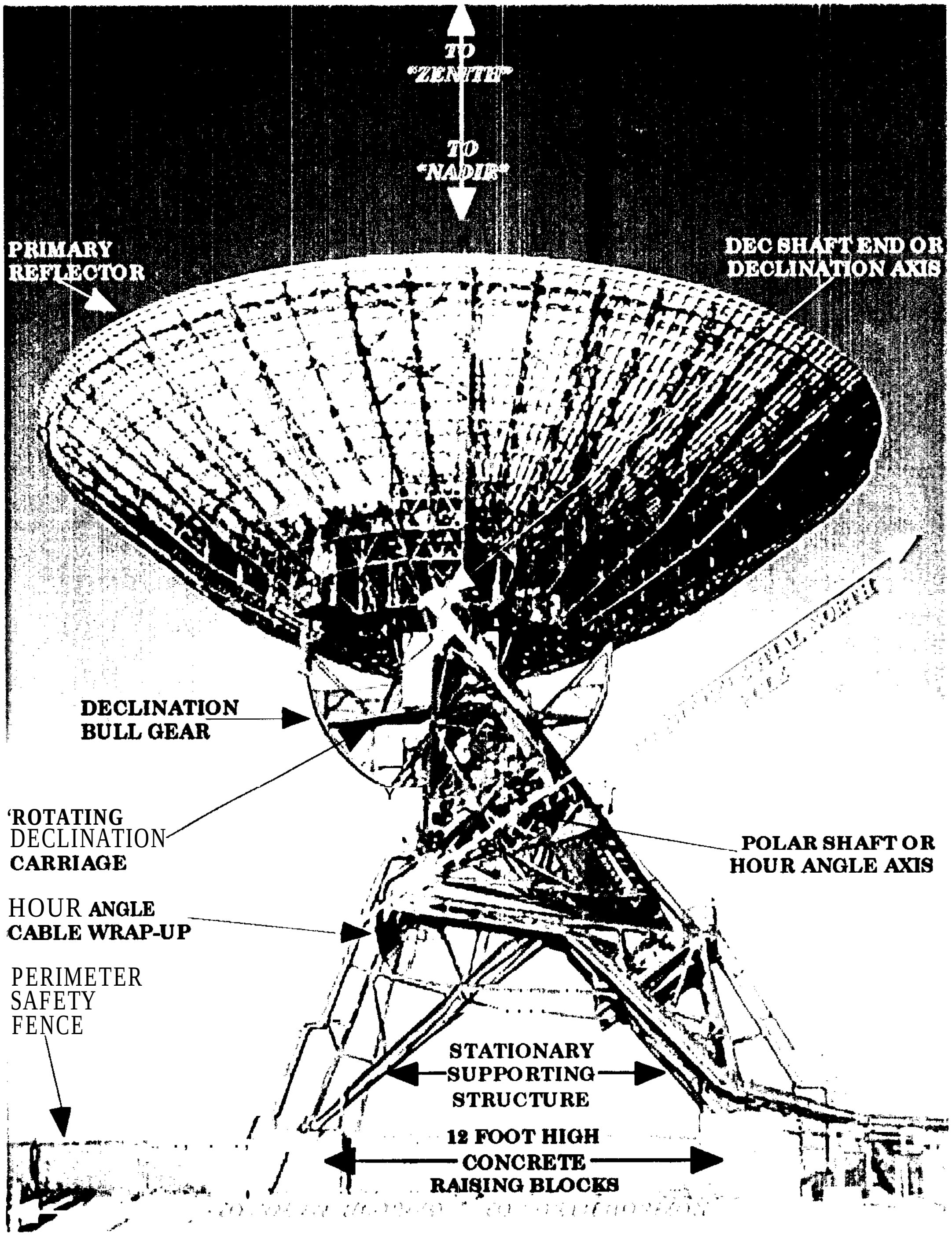


WEST-LOOKING VIEW OF THE GAVRT ANTENNA
& METEOROLOGICAL SENSORS

Meteorological sensors are also mounted on the surveillance TV camera mast and send meteorological data to the GAVRT Sun Spare-20 workstation in the control room. The purpose these sensors are twofold, to ensure that out-of-specification conditions (especially high winds) can be remotely monitored, and to allow users to monitor the effects of weather on GAVRT system performance (X-band in particular).

The Antenna

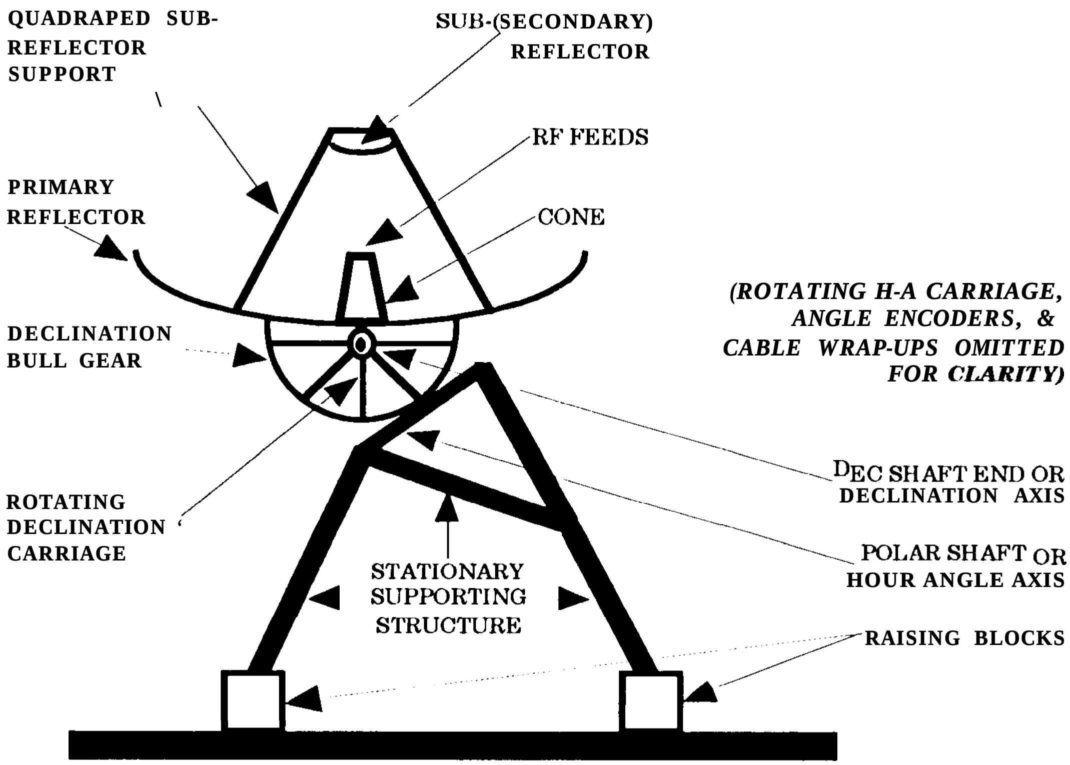
The GAVRT antenna is located at 116.805° west longitude and 35.300° north latitude and is mainly made of structural steel, except for the reflecting surfaces which are made of perforated (to allow water to drain during rain storms) sheet aluminum. When the antenna was enlarged from 26 to 34 meters it was necessary to raise the entire structure 12 feet to provide clearance between the primary reflector and the ground at low elevation angles. This was accomplished by raising and placing the three-legged stationary supporting structure on 12 foot high concrete raising blocks.



WEST-LOOKING VIEW OF THE GAVRT ANTENNA

The stationary supporting structure supports the hour angle skid (hour angle drive mechanism), the polar (hour angle axis) shaft bearings, the hour angle encoder (translates antenna hour angle angles into digital signals representing the antenna's position in the hour angle axis), the hour angle wrap -up, which allows electronic cables bet ween the stationary supporting structure and the hour angle carriage to move freely as the antenna is rotated in the hour angle axis, and the hour angle carriage itself (omitted from the diagram below).

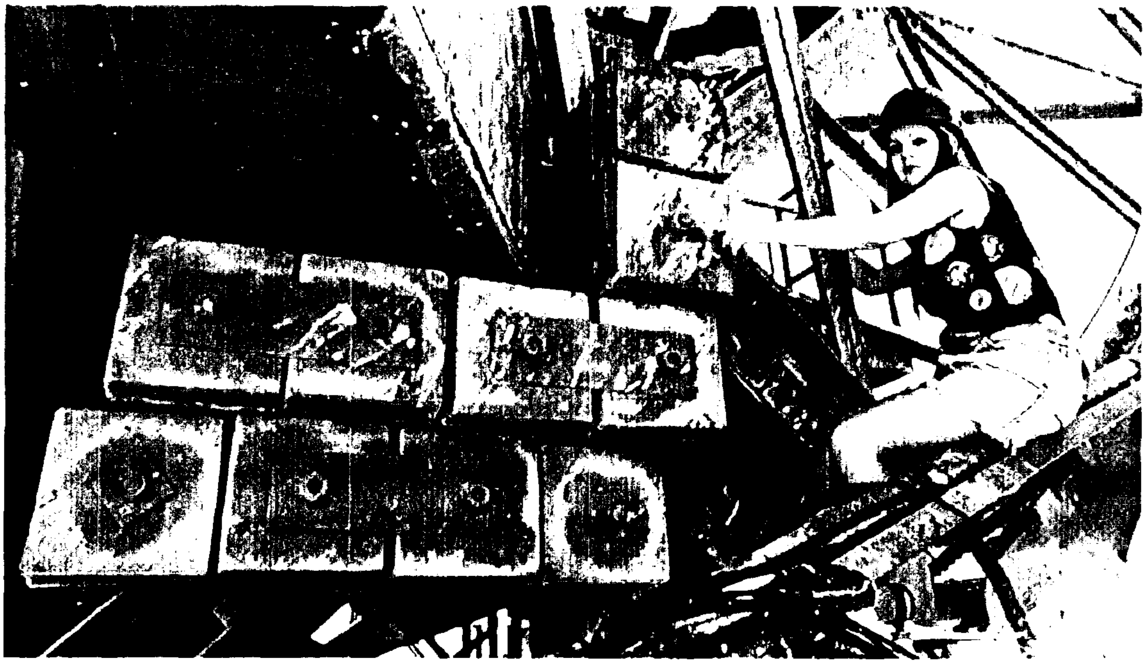
MAJOR STRUCTURAL ASSEMBLIES OF
THE GAVRT ANTENNA—WEST-LOOKING VIEW
(GAVRT LONGITUDE =116.805 DEGREES WEST, LATITUDE =35.300 DEGREES NORTH)



The hour angle skid is a steel platform bolted to the stationary supporting structure that provides a foundation for mounting the hour angle drive mechanisms. These mechanisms include the electric brakes, electric drive motors, antenna drive gear boxes with pinion output gears, and lubrication systems for the gear boxes. The hour angle axis is driven by two motor-gear box sets responding to slightly different drive commands for the purpose of maintaining zero pinion gear backlash between the two pinion gears and bull gear (the very large gear driven by the two pinion gears). The maximum rotation rate for either axis of the GAVRT is 0.250/second.

The declination carriage supports the same complement of equipment as the stationary supporting structure for hour angle, except that the declination carriage replaces the hour angle carriage, and the primary reflector and all equipment mounted above it, are fastened to the declination carriage. All of the equipment on the declination skid works in the same manner as for the hour angle skid. However , many of the declination axis hardware bits and pieces are physically only about two-thirds as large as those used on the hour angle axis. This is acceptable because the declination carriage does not have to control as much mass.

Both the hour angle and declination carriages are counter balanced with many lead weights that weigh approximately 100 lbs. each.



DECLINATION CARRIAGE COUNTER WEIGHTS

NOTE

Brooke Ardenski, the model used in many of these photographs, is 5' 2" tall.

The declination carriage positions the primary reflector, sub-reflector support assembly (quadrapod), sub-reflector, and the cone. The primary reflector, in tandem with the sub-reflector, collect and focus electromagnetic energy in the RF (Radio Frequency) feeds in the cone.

QUIZ

1. The GAVRT antenna is located at 116.805° west longitude and 35.300° north latitude and is mainly made of structural __________....
   Answer: Steel.

2. The hour angle skid is a steel platform bolted to the stationary supporting structure that provides a foundation for mounting the ____________________ drive mechanisms. **Answer: Hour angle.**

3. The maximum rotation rate for either axis of the GAVRT is _________ /second. **Answer: 0.25".**

4. Many of the declination axis hardware bits and pieces are physically only about ________________________ as large as those used on the hour angle axis. **Answer: 'ho-thirds.**

5. Both the hour angle and declination carriages are counter balanced with many lead ______________ .... **Answer: Weights.**

Inside of the GAVRT Control Room at GDSCC

Data Flow From Goldstone to the AVSTC

The Power Meter measures and digitizes the power level of the signal received by the antenna and sends the resulting data to the GAVRT Sun Spare-20 workstation in the control room at Goldstone.

GAVRT SUN WORKSTATION
IN THE CONTROL ROOM AT GOLDSTONE

The GAVRT Sun Sparc-20 workstation organizes the power meter's measurements, along with surveillance television still-frame video, monitor (GAVRT configuration and parameter data), and meteorological data generated by GAVRT devices, and sends them across a 56 kbps full duplex communications line to the AVSTC in Apple Valley.

Data Flow From The AVSTC to Goldstone

The GAVRT control command data blocks are sent from the AVSTC Sun Spare-20 workstation in Apple Valley to the GAVRT Sun Spare-20 workstation at Goldstone. This data is processed by the GAVRT Sun Sp arc-20 workstation, which commands GAVRT devices to various configurations including antenna pointing control, S and/or X-band reception, and power measurement and calibration.

Frequency and timing signals and time are provided to GAVRT devices by Goldstone's Deep Space Network Frequency and Timing Subsystem (FTS).

Either the commercial power grid, or emergency diesel motor-generator sets, provide electrical power for distribution to all GAVRT devices at Goldstone.

GAVRT control command blocks sent to the GAVRT Workstation are received from the AVSTC Workstation via the 56 kbps line, verified, and distributed to the appropriate GAVRT device(s) for execution.

QUIZ

1. The Power Meter ____ the power level of the signal received by the antenna . . . . **Answer: Measures and digitizes.**

2. The GAVRT Control ___________________________ Blocks arrive at the GAVRT Sun Spare-20 Workstation from the AVSTC Sun Spare-20 Workstation in Apple Valley. **Answer: Command.**

At the AVSTC

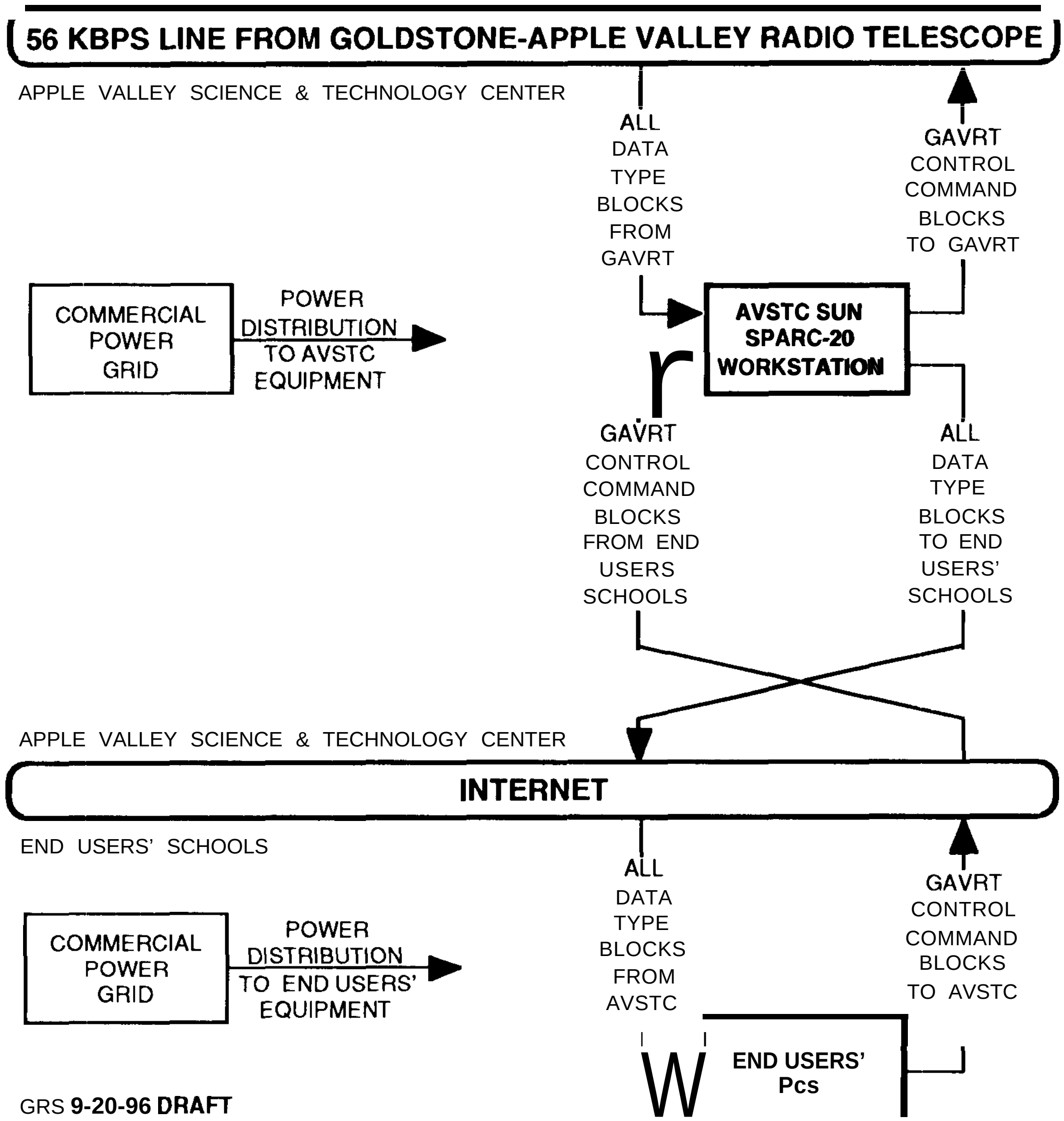
The AVSTC is staffed with AVUSD operators trained in the operation of the GAVRT system, the Sun Sparc-20 workstation, associated software, and the operation of downstream schools' personal computers and associated soft ware.

THE APPLE VALLEY SICENCE AND TECHNOLOGY CENTER

All data type blocks from Goldstone arrive at the AVSTC Sun Sparc-20 workstation via a 56 kbps full duplex communications line. The AVSTC workstation is remotely logged-onto by the GAVRT workstation in Apple Valley. All data type blocks from Goldstone are processed by the GAVRT Workstation, which in response to student, inputs, forwards requested data types to the end users' PCs via the internet, and displays GAVRT surveillance TV images on the AVSTC Sun Spare-20 workstation.

SIMPLIFIED GAVRT SYSTEM SIGNAL/DATA FLOW DIAGRAM

PART 2—SYSTEM ELEMENTS AT
APPLE VALLEY SCIENCE AND TECHNOLOGY CENTER & END USERS' SCHOOLS



QUIZ

1. All data type blocks from Goldstone arrive at the AVSTC Sun Sparc-20 Workstation via a ________________ full duplex communications line.
Answer: 56 kbps.

At the End Users Schools

End Users' PCs receive and may record all data type blocks (except surveillance TV) from the AVSTC for non-realtime data analysis data analysis. As of the October 1997, the bandwidth constraints between the AVSTC and client schools prohibit forwarding of surveillance TV images to the client schools.

End Users' PCs have applications software installed to support the downloading, recording, and non-realtime analysis of GAVRT observational data.

The GAVRT control command blocks to AVSTC are originated at the end users' PCs using provided applications software and sent to the AVSTC workstation via the internet.

All end users school's devices are powered from the commercial power grid.

So, the end user's PCs are logged onto the GAVRT workstation in Apple Valley, which is logged onto the GAVRT workstation at Goldstone, allowing users at the remotely-located client schools to operate the GAVRT system.

QUIZ

1. . .. bandwidth constraints between the AVSTC and client schools prohibit forwarding of ______________________________ images to the client schools. **Answer: Surveillance TV.**

2. End Users' PCs have applications software installed to support the downloading, recording, and non-realtime analysis of GAVRT _____________________ data. **Answer: Observational.**

THEORY OF OPERATION—FUNCTIONAL BLOCK DIAGRAMS

Learning Objectives for this Section

Completion of this section will enable learners to:

- Describe the function of the sub-reflector
- Characterize the signals passed from the sub-reflector to the dichroic plate
- Describe the function of the RF mirror
- Describe the function of the S-band feed horn
- Describe the function of the polarizer
- Describe the function of the microwave switch
- Describe the function of the coupler
- Describe the function of the LNA
- Characterize the signals passed from the LNA to the S & X-band downconverter
- Describe the function of the S & X-band downconverter
- Characterize the signals passed from the S & X-band downconverter to the distribution amplifier
- Describe the function of the power meter
- Characterize the data passed from the power meter across the IEEE-488 bus.
- Characterize the signal passed from the distribution amplifier through the S/X-band selector switch to the spectrum analyzer
- Describe the function of the spectrum analyzer

- Characterize the data passed from the spectrum analyzer across the IEEE-488 bus

- Describe the function of the serial controller associated with the distribution amplifier

- Characterize the data passed between the serial controller and the IEEE-488 bus

- Describe the function of the X-band rain blower

- Characterize the signals passed between the X-band rain blower and the relay box

- Describe the function of the relay box

- Characterize the data passed between the relay box and its associated serial controller

- Describe the function of the ambient load

- Characterize the signals passed from the ambient load to the quartz thermometer

- Describe the function of the quartz thermometer

- Characterize the data passed between the quartz thermometer and the temperature display

- Describe the function of the temperature display

- Characterize the data passed between the temperature display and the IEEE-488 bus

- Describe the function of the S & X-band noise diodes

- Characterize the data passed from the S & X-band noise diodes to the serial controller

- Describe the function of the sub-reflector controller

- Characterize the data passed between the sub-reflector controller and the relay box

- Describe the function of the weather station
- Characterize the data passed from the weather station to its associate serial controller
- Describe the function of the surveillance television
- Characterize the signals passed between the surveillance television and station controller Wizard
- Describe the function of the time code translator
- Characterize the data passed between the time code translator and station controller Wizard
- Describe the function of the antenna control subsystem
- Characterize the data passed between the antenna control subsystem and station controller Wizard
- Describe the function of the integrity fence interlock
- Characterize the signal passed from the integrity fence interlock and station controller Wizard
- Characterize the signals passed from station controller Wizard to the floodlights
- Characterize the data passed between station controller Wizard and workstation Oz
- Describe the bandwidth of the communications line between station controller Wizard and workstation Oz
- Describe the function of workstation Oz
- Identify the communications medium between workstation Oz and PC/Mac personal computer Dorothy
- Characterize the data passed between workstation Oz and PC/Mac personal computer Dorothy

- Describe the overall purpose of the universal time function

- Describe the overall purpose of the GAVRT monitor and control function

Introduction

In this section the GAVRT system theory of operation will be discussed down to the functional block diagram level of detail, in terms of describing the inputs to, functions of, and the outputs of each functional block. If you are unfamiliar with the astronomical terms used in this section, such as right ascension, declination, hour angel, celestial poles, etc., please complete the "Basics of Radio Astronomy" learning module before proceeding. The "Basics of Radio Astronomy" learning module may be downloaded without charge from URL:

http: //www.jpl.nasa.gov/radioastronomy/

Several **highlighted** versions of the following functional block diagram of the GAVRT System will be used to support the presentation of this section.

GAVRT Functional Block Diagram

The following drawing represents all of the major functions of the GAVRT System, including calibration configurations. The geographical boundaries of the domains within which the system elements reside are shown as dotted lines, and the domains are labeled in *underlined italics.* Each box represents a function of the GAVRT system. Several radio frequency elements, the sub-reflector, dichroic plate, etc., are shown as pictographs. When the signal/data arrows are single-headed, they are showing the direction of the signal/data flow. When they are double-headed, they indicate that there is data flow in both directions. When the interconnecting logical wires carry electricity that is RF (radio frequency) and analog in nature, they are referred to as signal lines. When the interconnecting logical wires carry electricity that is binary and digital in nature, they are referred to as data lines. Annotations to the diagrams are presented in *italics.*

The interconnecting lines and arrows represent logical interfaces that often consist of many wires that have been simplified into single wires here for clarity. Also omitted are many circuit elements that perform calculations on, amplify, and attenuate signal and/or data flow. A discussion of these elements is not required to attain a functional understanding of the GAVRT System.

The microwave switch symbols, shown here as a square, enclosing a circle, enclosing two quarter-circles, are two-position switches that pass RF (Radio Frequency) signals as indicated by the quarter-circles, or by rotating the quarter-circles 90 degrees clockwise or counter-clockwise to configure the alternate microwave pathway.

GAVRT FUNCTIONAL BLOCK DIAGRAM

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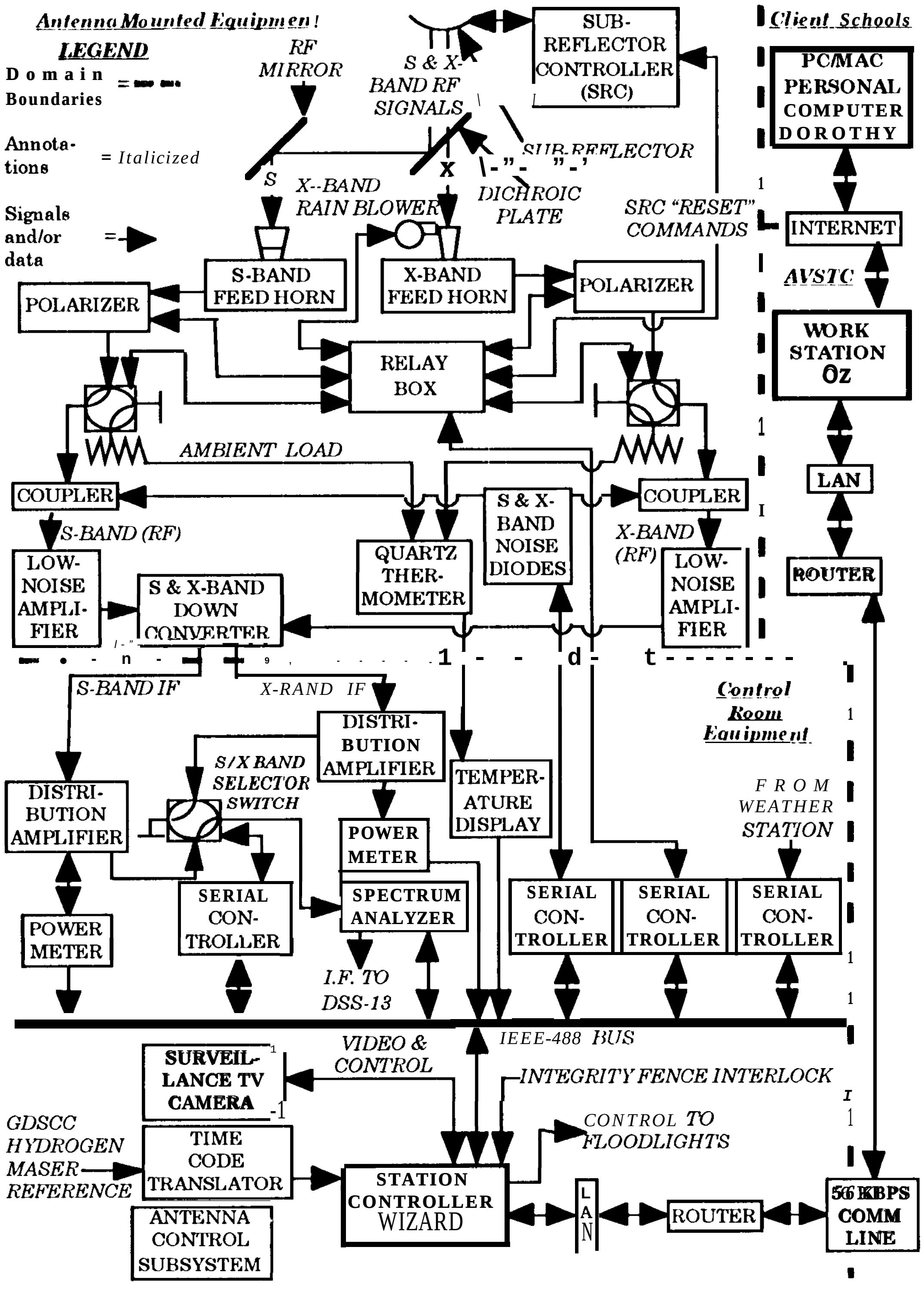


Universal Time Functional Block Diagram

NOTE

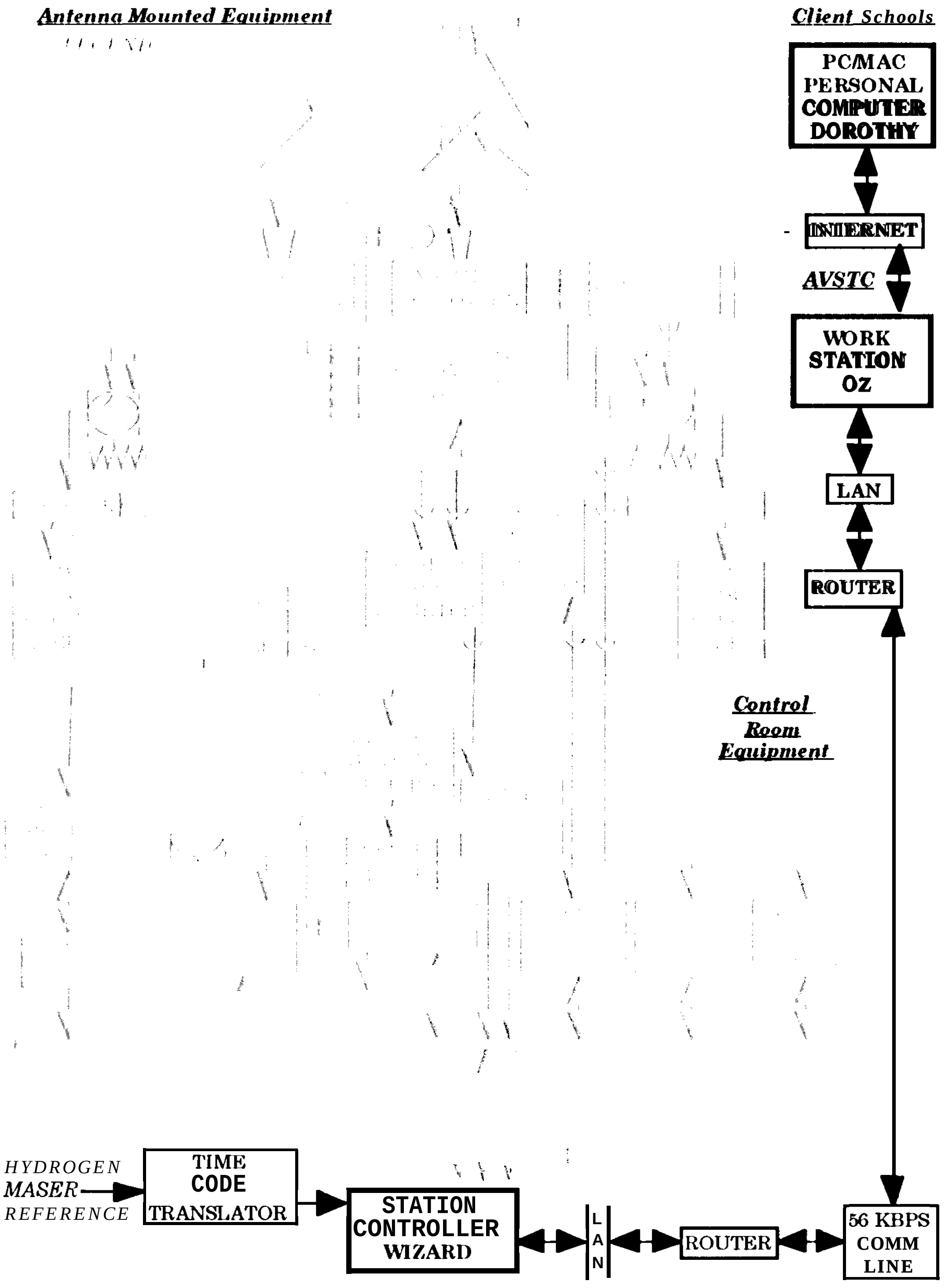
> Take a moment to review the following diagram, Universal Time Functional Block Diagram. Notice that only the elements of the overall block diagram that are under discussion are **highlighted.** This approach will be used to focus attention in turn on each functional area of the diagram until the full set of GAVRT system functions have been presented.

As in all astronomical activities, accurate and precise time is required. The DSNS (Deep Space Network's) Frequency and Timing System (FTS) at Goldstone provides extremely accurate and precise timing and frequency signals and data to all of the antenna sites at GoldStone. The hydrogen masers used in the DSN (Deep Space Network) are configured to operate in the oscillation mode. In this mode hydrogen masers are extremely stable oscillators that provide the GAVRT frequency and timing equipment a very stable reference frequency that is both accurate. and precise.

The following diagram shows how data arriving from the GAVRT system at the "Dorothy" (client school) personal computers is time-tagged.

UNIVERSAL TIME FUNCTIONAL BLOCK DIAGRAM

GRS: *8-28-97*



The Goldstone hydrogen maser reference signal is provided to the time code translator in the control room at the GAVRT site to update the time code translator's clock. The time code translator delivers very accurate and precise time to station controller" Wizard', which tags (attaches) time to each data wrapper (data packet) sent out from "Wizard'.

Various kinds of data, as we will see on the following diagrams, are sent from Wizard, across a LAN (Local Area Network) to a router (a device that "routes" data packets to their correct destinations), and onto a commercial 56 kbps Comm (Communications) line.

The other end of this line is connected through a router, across a LAN (Local Area Network) to workstation "OZ" at the AVSTC (Apple Valley Science and Technology Center) in Apple Valley, California.

Using FTP (File Transfer Protocol) techniques, workstation "OZ" sends time-tagged data wrappers across the internet to PC/Mac personal computer "Dorothy" at the client school. The PC/Mac personal computer "Dorothy" displays accurately and precisely time-tagged GAVRT system data.

The GAVRT system <u>does not</u> adjust the clock in the PC/Mac personal computer "Dorothy". To learn how to accurately set the clock on "Dorothy" computers, visit the United States Navel Observatory at URL

http: //tycho.usno.navy .mil/what.html

or at URL:

http: //tycho.usno.navy. mil/time.html

QUIZ

1. . ..hydrogen masers are extremely stable oscillators that provide the GAVRT frequency and timing equipment a very stable reference frequency that is both ________________________________ **Answer: Accurate and precise.**

2. . . . Station controller "Wizard, which tags (attaches) ____________ to each data wrapper (data packet) sent out from "Wizard". **Answer: Time.**

3. Using ______________________________ techniques, Workstation "OZ" sends time-tagged data wrappers across the internet to PC/Mac personal computer "Dorothy" . . . . **Answer: FTP, or File Transfer protocol**

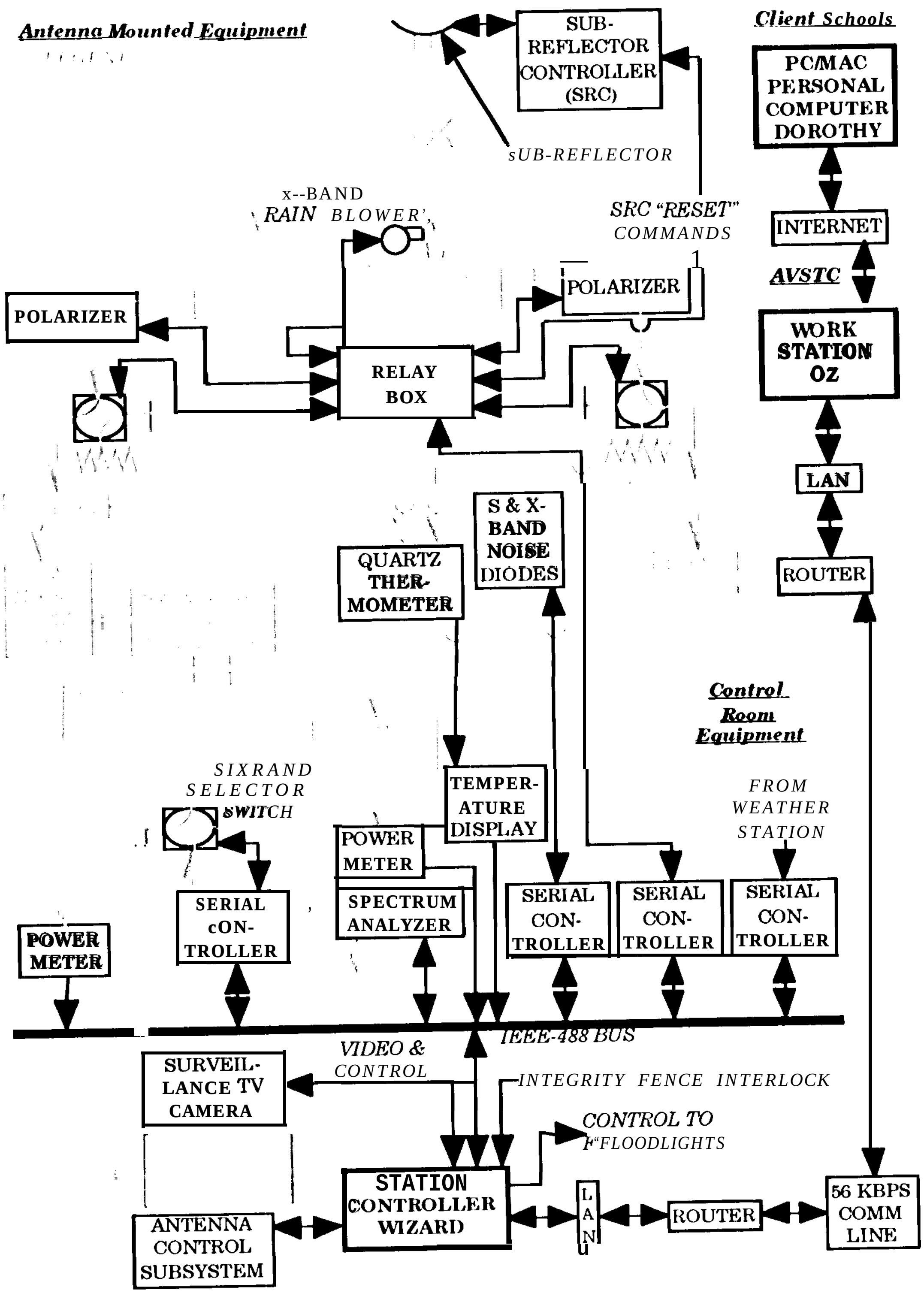
Monitor and Control Functional Block Diagram

The overall GAVRT monitor and control function monitors the configuration and performance parameters of the GAVRT system and delivers this data to the PC/Mac personal computer "Dorothy" at the client school. This function also develops system commands (instructions to the GAVRT system) and delivers them to the appropriate system elements at the AVSTC (Apple-Valley Science and Technology Center), and at the GAVRT site at Goldstone for execution.

Observational data (from a astronomical source) is not delivered by the GAVRT Monitor& Control function, but will be addressed on the S-Band and X-Band Observational Functional Block diagrams presented later in this section.

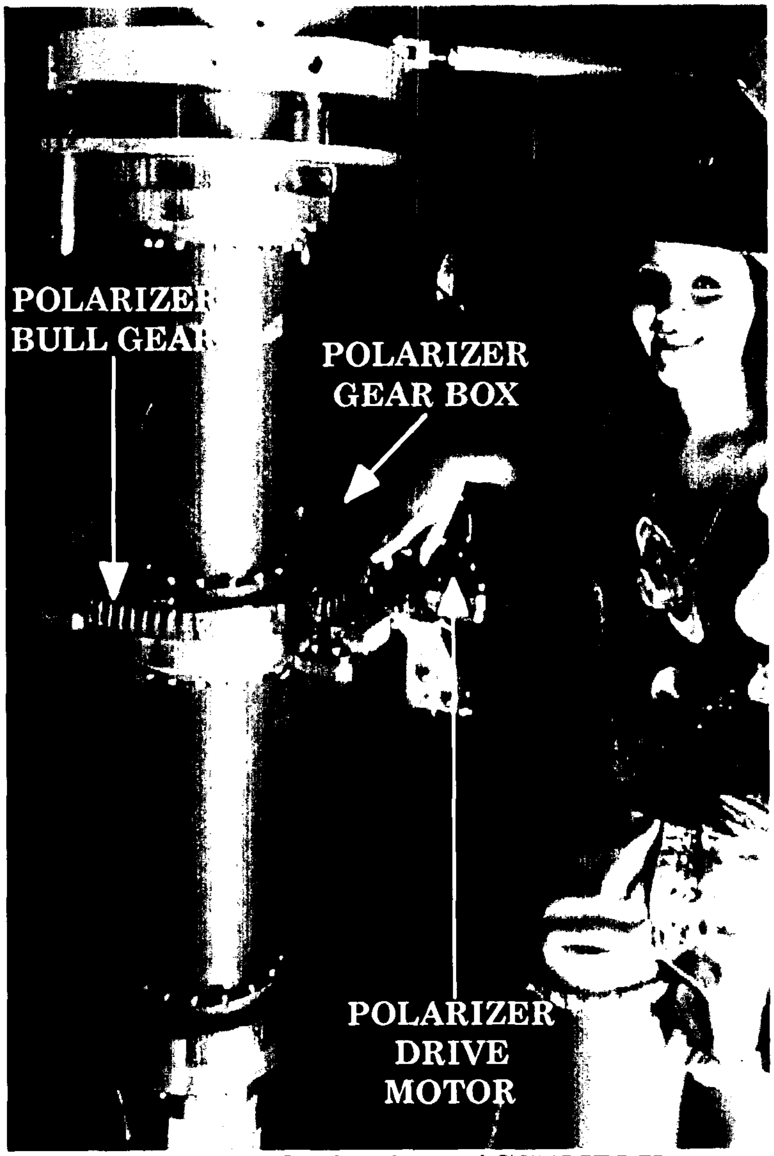
MONITOR & CONTROL **FUNCTIONAL** BLOCK **DIAGRAM**

GRS: 8-28-97



The GAVRT Monitor& Control function measures the configuration and performance of various GAVRT system elements at the GAVRT site at Goldstone, and accesses specified data at the "OZ" computer at the AVSTC (Apple Valley Science and Technology Center). Also, commands prepared at the "Dorothy" personal computer at the client school, are forwarded through "OZ", and on to "Wizard" at Goldstone for execution.

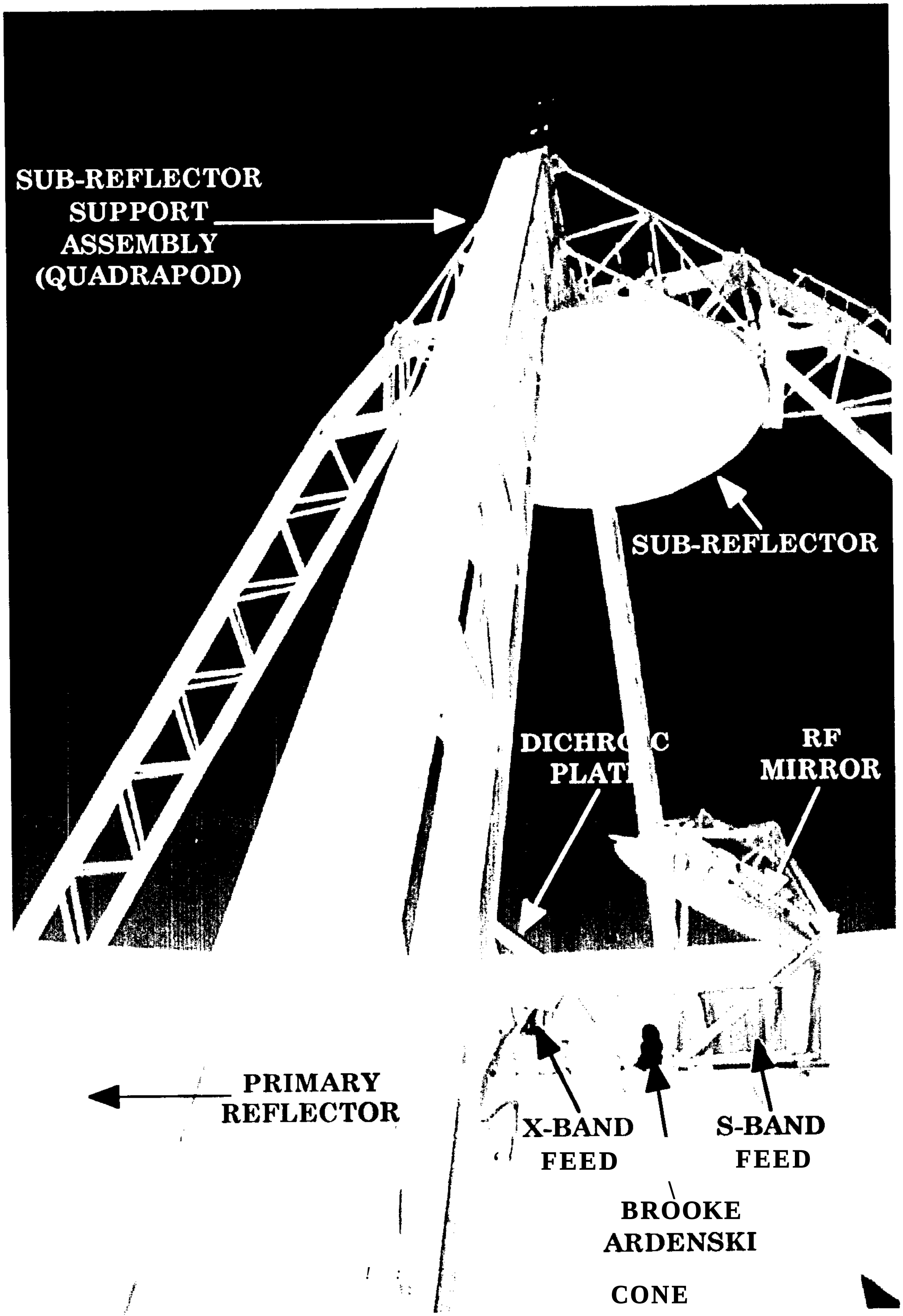
Regarding the monitor function, the S and X-band polarizers send polarizer angle and mode data through the relay box, serial controller, IEEE-488 bus, to the station controller "Wizard', in the control room at Goldstone.



S-BAND POLARIZER ASSEMBLY,
INSIDE THE RF CONE ON THE ANTENNA

Sub-reflector, and the S and X-band microwave switch positional data follow the same path to "Wizard". Both S and X-band power meters, spectrum analyzer, temperature display (system temperature), and "from weather station" meteorological data are sent directly across the IEEE-488 bus to "Wizard'. The Antenna Control Subsystem provides GAVRT antenna angle data, and the surveillance TV camera provides still frame video directly to "Wizard'.

The following photograph depicts GAVRT antenna sub-reflector.



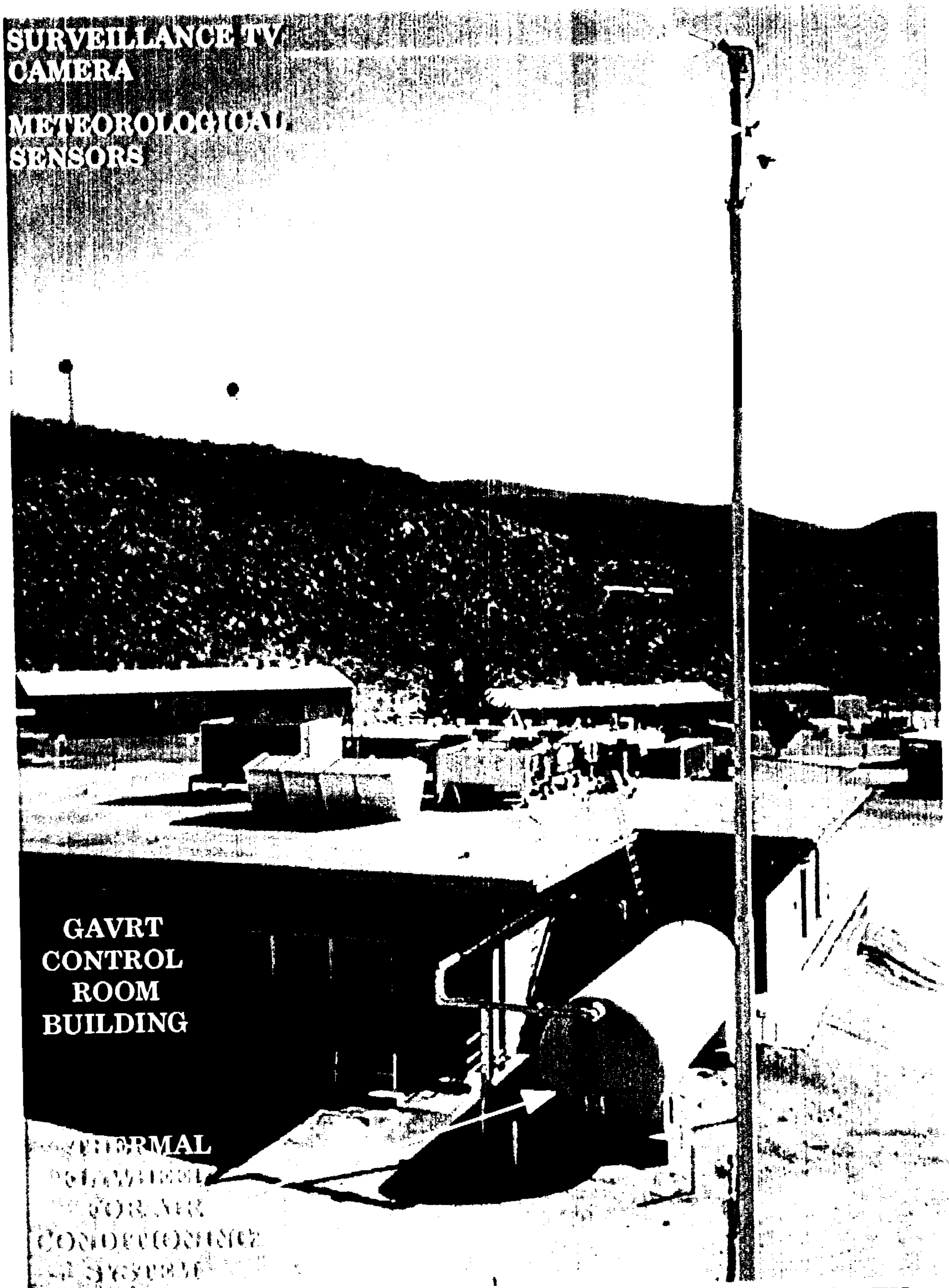
GAVRT ANTENNA SUB-REFLECTOR ASSEMBLY

The GAVRT antenna integrity fence interlock system interrupts the drive signal to the antenna drive system if the perimeter fence looses its integrity, stopping all antenna movement immediately. In a like manner, the system also includes interlocked gate-covers for each of the two access ladders on the antenna. Opening either of these two access gates also stops all antenna movement immediately in the same manner as employed by the fence.

This system was installed to prevent vehicles and/or equipment from being moved into the area under the antenna without interrupting antenna movement. During heavy maintenance or overhauls the fence segments can be removed to provide access for heavy equipment.

GAVRT ANTENNA PERIMETER INTEGRITY FENCE

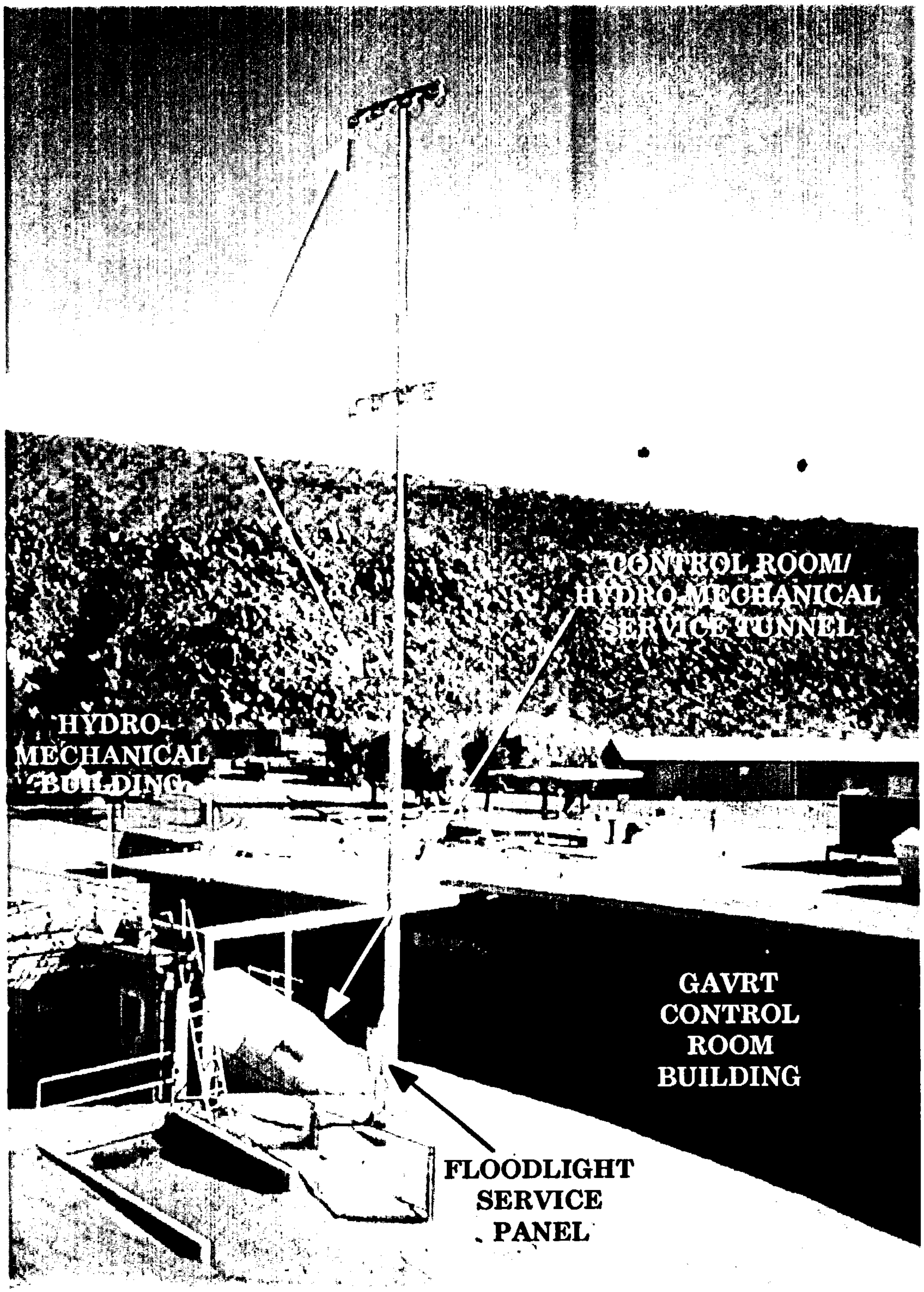
The next photograph shows the physical location of the survei lance TV camera and the weather station sensors.



GAVRT METEOROLOGICAL SENSORS & SURVEILLANCE TV

Commands that tell the GAVRT what to do are originated at the PC/Mac personal computer "Dorothy", are forwarded across the internet to workstation "OZ" at the AVSTC and on across a LAN, through a router, and across a 56 kbps communications line to the GAVRT control room at Goldstone.

Command data arriving at the GAVRT control room passes through a router and LAN, and through station controller wizard, directs it to the appropriate equipment, like the antenna floodlights shown on the next page.



GAVRT ANTENNA FLOODLIGHTS & CONTROL ROOM BUILDING

Other GAVRT equipment controlled by station controller wizard includes: surveillance TV camera, Antenna Control Subsystem, S-X selector switch, spectrum analyzer, power meters, and S & X-band noise diodes.

QUIZ

1. The overall GAVRT monitor and control function monitors the ______________________________ parameters of the GAVRT system and delivers this data to the PC/Mac personal computer "Dorothy" at the client school. **Answer: Configuration and performance.**

2. ... commands prep ared at the "Dorothy" personal computer at the client school, are forwarded through "OZ", and on to" Wizard at Goldstone for ______________________. **Answer: Execution.**

3. The integrity fence was installed to prevent vehicles and/or equipment from being moved into the area under the antenna without interrupting antenna ______________________. **Answer: Movement.**

S-Band Calibration Functional Block Diagram

To establish and maintain accurate and precise calibration of the GAVRT system, it must be routinely calibrated. This task is performed by trained personnel at the AVSTC (Apple Valley Science & Technology Center). However, system users should have a general understanding of the calibration functional block diagrams to appreciate how the system is calibrated for the precise and accurate measurement of astronomical signals.

When acquiring the very weak electromagnetic radiation from astronomical sources the amount of noise (random electron movement) created by each RF (Radio Frequency) system element, by man-made noise, and by the background noise of free space, makes it difficult to distinguish between the signal and noise components of the signal arriving at the LNA (Low Noise Amplifier).

NOTE

Do not confuse the terms *audio noise* and *RF noise*.

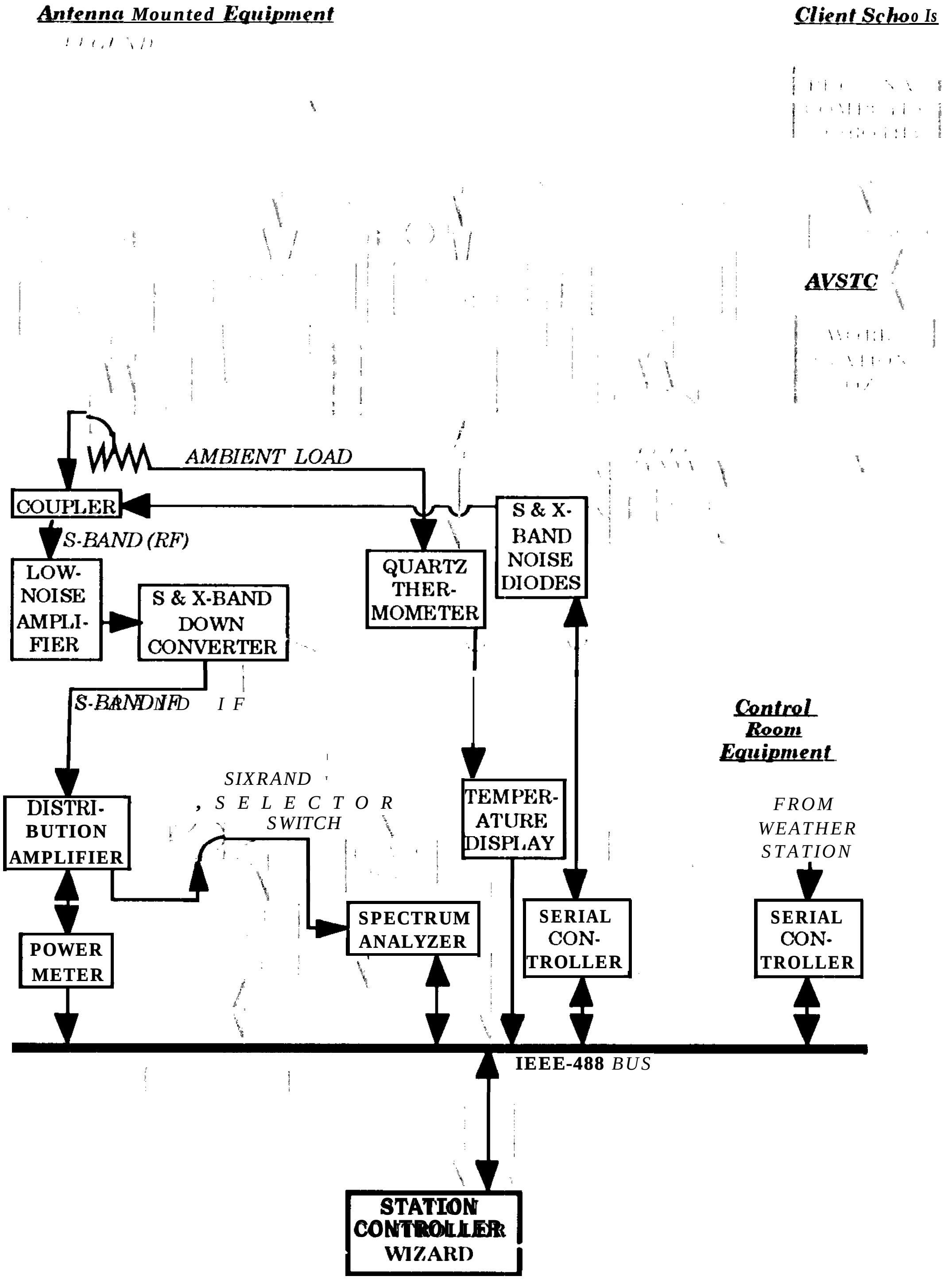
Audio Noise refers to unorganized audio frequency (0-20 khz) sound waves propagated through a medium, such as air.

RF Noise refers to unorganized (random) radio frequency waves.

Unlike sound waves, electromagnetic waves do not require a **medium** for propagation, and can be propagated through space. Noise is contributed by the random electron movements of each system element, the atmosphere, and the background noise of deep space.

S-BAND CALIBRATION FUNCTIONAL BLOCK DIAGRAM

GRS: 8-28-97



At the beginning of the calibration procedure, the S & X-band noise diodes are commanded "Off' by the station controller wizard. Observe on the above diagram that the S & X-band selector switch is positioned to route one of the outputs of the S-band distribution amplifier to the spectrum analyzer. Also, the microwave switch mounted on the antenna is positioned to connect the ambient load to the coupler. This configuration removes the deep space background noise, RFI (radio frequency interference--man-made noise), and atmospheric noise from the system calibration measurements.

NOTE

Some of the longer signal/data flow descriptions in this module are presented in outline form for clarity.

The station controller wizard sends commands:

1. Across the IEEE-488 bus,

2. Through a serial controller,

3. To the S & X-band noise diodes to turn them "On" or "Off'.

NOTES

When the diodes are "Off', the power meter is measuring the quiescent system noise.

When the diodes are "On" the power meter is also measuring the system noise level, but with a calibrated quantity of injected noise added to the signal path by the ambient load.

The noise created by the X-band ambient load is:

1. The signal is then passed through the coupler (a device that merges two RF signals into a single composite signal), where the output of the S & X-band noise diodes are added to the noise signal when the diodes are "On",

2. Onto the S-band LNA (Low Noise Amplifier), a device specifically engineered to amplify the signal while adding minimal noise to the overall system noise),

3. Through the S & X-band down-converter (a device that converts the RF [Radio Frequency] signals into a proportional IF [Intermediate Frequency--a few megahertz in this case] signal),

4. Through the S-band distribution amplifier that maintains the IF signal level and sends the signal:

    a. Through the S-X-band selector switch,

        1. Through the spectrum analyzer, which is used to display RF spectral information used to monitor the presence of man-made RF interference during the calibrations,

        2. Across the IEEE-488 bus,

        3. To station controller wizard, for recording, display and analysis.

    b. And through the power meter, a device that measures the IF signal and converts [A-D, analog to digital] it into equivalent data that is forwarded:

        1. Across the IEEE-488 bus,

        2. To station controller wizard, for recording, display and analysis.

Meteorological data is important to noise calculations because variations in the water vapor content of the atmosphere dramatically changes the measured system temperature (Ts), especially at X-band. Signals from the weather station are;

1. Passed through the serial controller,

2. Across the IEEE-488 bus,

3. To the station controller "Wizard" for recording, forwarding, analysis, and display.

The temperature of the ambient load is measured by the quartz thermometer, a very precise electronic thermometer, which sends a signal to:

1. The temperature display, which displays and sends the derived temperature data to,

2. The station controller "Wizard' for processing and display.

During the calibration procedure the S & X-band noise diodes are switched "On" and "Off', while "Wizard' analyzes the changes in power (strength) of the signal measured by the power meter, and factors in the temperature of the ambient load, to calculate Ts (System Temperature). Weather station and spectrum analyzer data are used by AVSTC operators to verify that non-astronomical conditions are not causing false readings during the calibration procedure.

QUIZ

1. RF Noise refers to unorganized (random) ___________________________________ waves. **Answer: Radio frequency.**

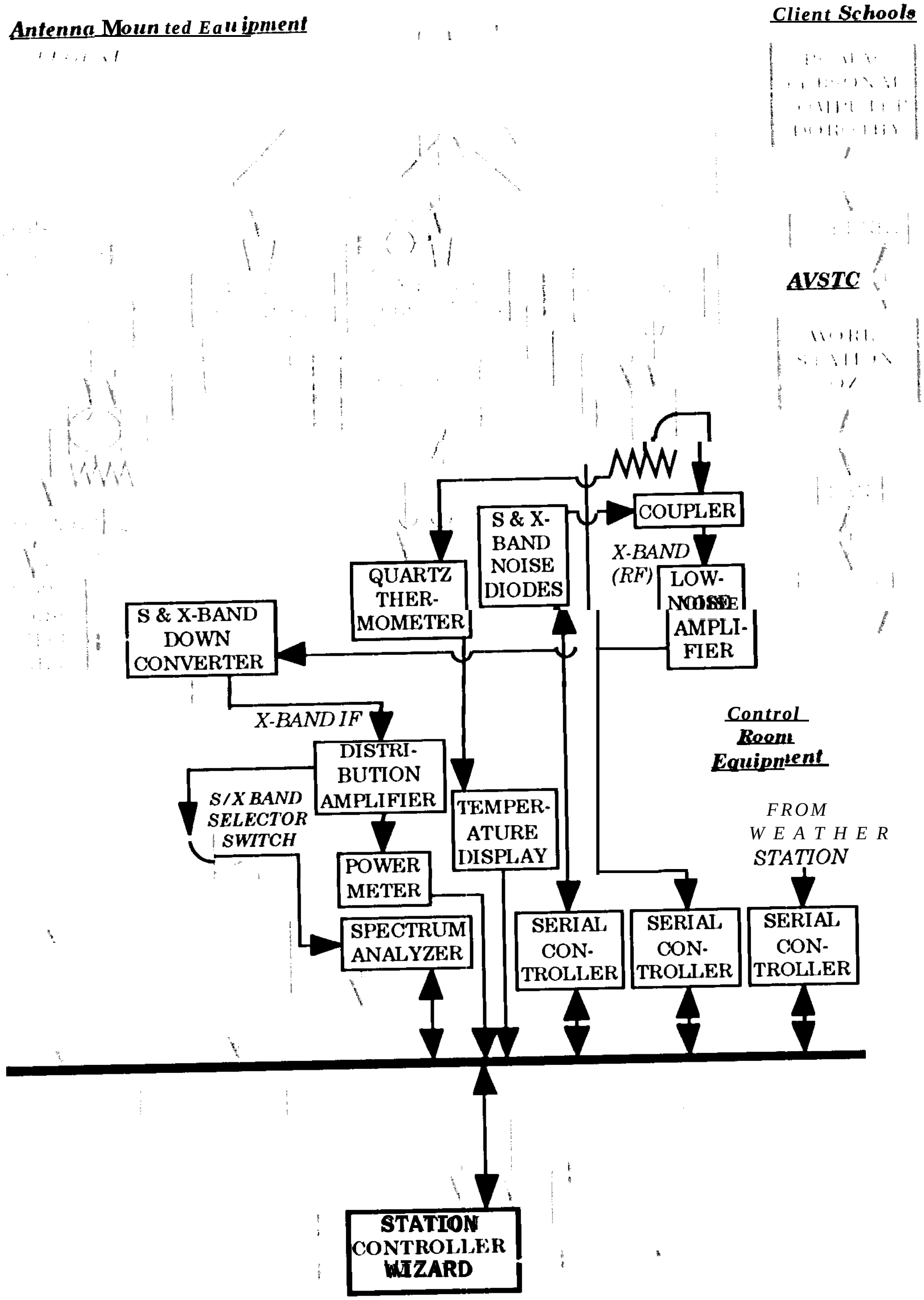
2. . . electromagnetic waves do not require a ________________ for propagation . . . . **Answer: Medium.**

X-Band Calibration Functional Block Diagram

In principal calibration of the X-band portions of the GAVRT system are the same as for the S-band portions. However, keep in mind that atmospheric water vapor content (humidity) has much more effect on X-band performance than it does on S-band performance.

X-BAND CALIBRATION FUNCTIONAL BLOCK DIAGRAM

GRS: 8-28-97



At the beginning of the calibration procedure, the S & X-band noise diodes are commanded “Off’ by the station controller “Wizard’. Observe on the above diagram that the S & X-band selector switch is positioned to route one output of the X-band distribution amplifier to the spectrum analyzer. Also, the microwave switch mounted on the antenna is positioned to connect the ambient load to the coupler. This configuration removes the deep space background noise, RFI (radio frequency interference--man-made noise), and atmospheric noise from the calibration measurements.

The station controller “Wizard’ sends commands:

1. Across the IEEE-488 bus,

2. Through a serial controller,

3. To the S & X-band noise diodes to turn them “On” and “Off.

The noise created by the X-band ambient load is:

1. Passed through the coupler (a device that merges two RF signals into a single composite signal), where the output of the S & X-band noise diodes are added to the noise signal when the diodes are “On”,

2. To the X-band LNA (Low Noise Amplifier), a device specifically engineered to amplify the signal while adding minimal noise to the overall system noise),

3. Through the S & X-band down-converter, a device that converts the RF (Radio Frequency) signals into a proportional IF (Intermediate Frequency) --a few megahertz in this case] signal,

4. Through the X-band distribution amplifier that maintains the IF signal level and sends the signal:

    a. Through the S-X-band selector switch,

        1. Through the spectrum analyzer (used to display RF spectral information used to monitor for the presence of man-made RF interference during the calibrations),

        2. Across the IEEE-488 bus,

3. To station controller "Wizard", for recording, forwarding, display and analysis.

b. And through the power meter, a device that measures the IF signal and converts (A-D, analog to digital) it into equivalent data that is forwarded:

1. Across the IEEE-488 bus

2. To station controller "Wizard', for recording, display and analysis.

Meteorological data is important to noise calculations because variations in the water vapor content of atmosphere dramatically change the measured system temperature (Ts), especially at X-band, Signals from the weather station are;

1. Passed through the serial controller,

2. Across the IEEE-488 bus,

3. To the station controller wizard for recording, forwarding, analysis, and display.

The temperature of the ambient load is measured by the quartz thermometer, a very precise electronic thermometer, which sends a signal to the temperature display, which displays and sends the derived temperature data to the station controller wizard for processing and display.

During the calibration procedure the S & X-band noise diodes are switched "On" and "Off, while "Wizard' analyzes the changes in power (strength) of the signal measured by the power meter to calculate Ts (system temperature).

QUIZ

1. ...water vapor content (humidity) has much more effect on _______________ performance than it does on S-band performance.
Answer: X-band.

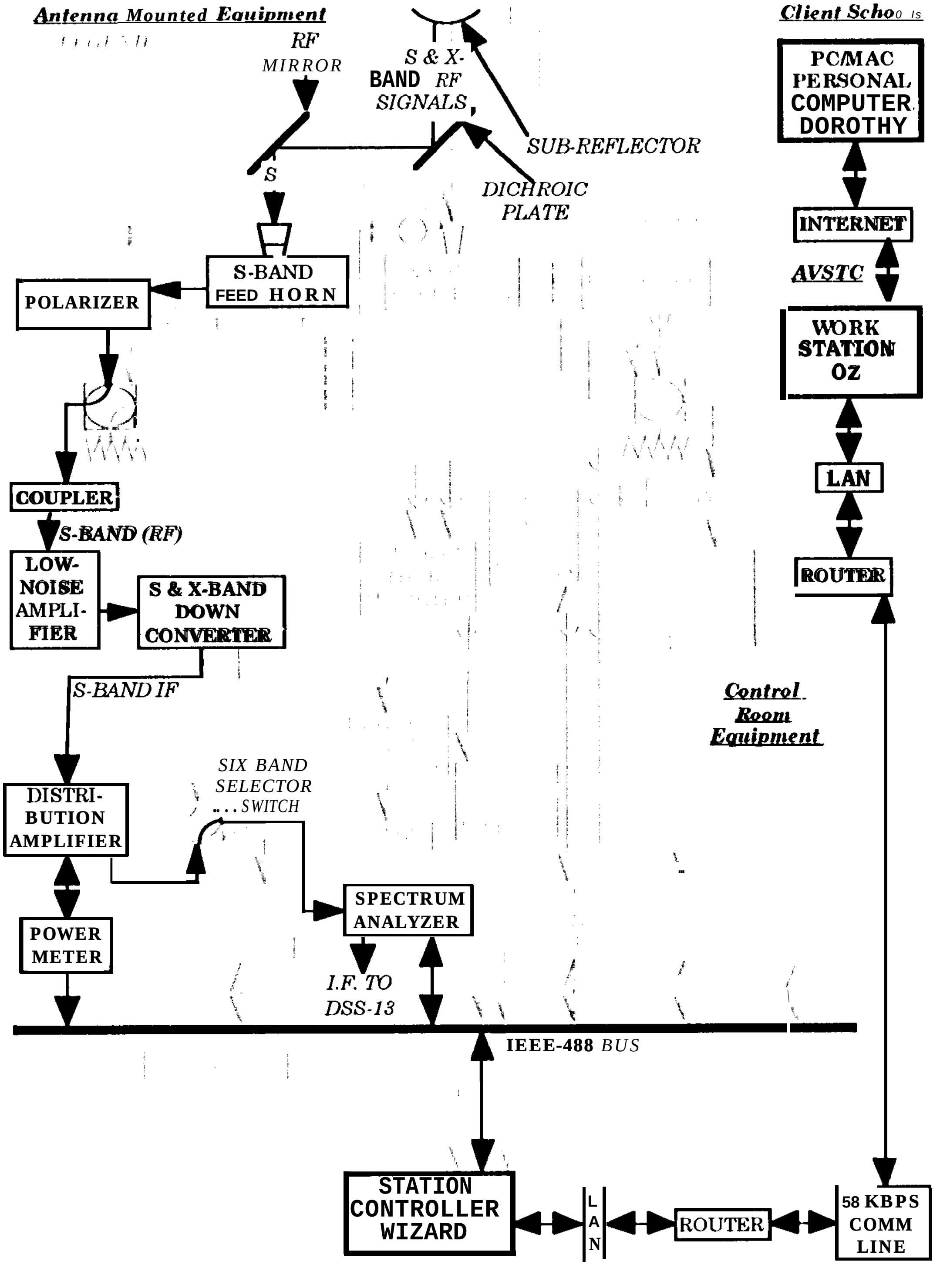
S-Band Observational Functional Block Diagram

GAVRT signal flow begins at an astronomical RF (Radio Frequency) source. If you have not done so already, you should complete the "Basics of Radio Astronomy" learning module before continuing with this module. The "Basics of Radio Astronomy" is at URL:

http://www.jpl.nasa.gov/radioastronomy/

S-BAND OBSERVATIONAL FUNCTIONAL BLOCK DIAGRAM

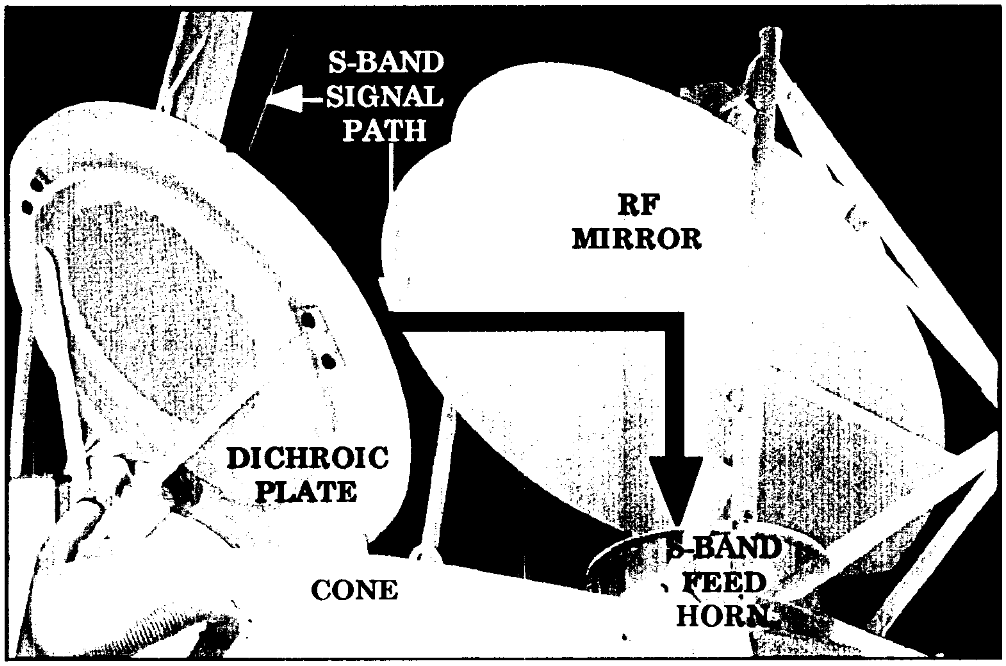
GRS: 8-28-97



S-band RF (Radio Frequency) electromagnetic energy arriving at the GAVRT antenna primary reflector is bounced off of:

1. The sub-reflector (also known as the secondary reflector), which reflects the signal onto,

2. The dichroic plate, which using the same principles as the door on a microwave oven, presents a mirror to S-band electromagnetic energy and reflects it to,



S-BAND FEED

3. The RF mirror, which reflects the S-band signal into,

4. The S-band feed horn where it is focused and passed,

5. Through the S-band polarizer and is passed,

6. Through the S-band microwave switch to,

7. The coupler, which allows the calibrated noise to be injected into the system during calibration procedures, and to,

8. The S-band Low Noise Amplifier (LNA), which amplifies the signal level with minimal noise addition, and to,

9. The S & X-band down converter, which translates the S-band signal into a proportional IF (Intermediate Frequency, in this case a few megahertz), and to,

10. The S-band distribution amplifier, which maintains the proper signal level, and to,

    A. The S & X-band selector switch, which routes the signal to the Spectrum Analyzer, which formats and displays amplitude verses frequency plots of the received signal and forwards this data to the station controller "Wizard".

    B. The S-band power meter which measures the power of the signal and forwards a digital expression of that measurement across the IEEE-488 bus to:

NOTE

The "I. F. To DSS- 13" output of the spectrum analyzer has been provided to allow GAVRT spectrum analyzer data to be sent to 1) S- 13 (Deep Space Station-13, Venus Site) for processing. This capability may be implemented in the future.

11. Station controller "Wizard, which forwards signal power verses time data across,

12. The LAN (Local [to Goldstone] Area Network), and through,

13. The router at GAVRT-Goldstone, and through,

14. The 56 kbps Comm line, and through,

15. The router at the AVSTC, and across,

16. The LAN at the AVSTC, to,

17. Workstation "OZ", at the AVSTC.

18. Users of the PC/Mac personal computer "Dorothy" at the client schools may download S-band data by using FTP (File Transfer Protocol) techniques causing this data to,

19. To be sent from the workstation "OZ", at the AVSTC

20. Across the internet,

21. To the PC/Mac personal computer "Dorothy" for display/recording.

QUIZ

1. GAVRT signal flow begins at an ______________________ RF (Radio Frequency) source. **Answer: Astronomical.**

2. The dichroic plate presents a _____________ to S-band electromagnetic energy. **Answer: Mirror.**

X-Band Observational Functional Block Diagram

Once again, if you have not done so already, you should complete the "Basics of Radio Astronomy" learning module before continuing with this module. The "Basics of Radio Astronomy" learning module is located at URL:

http: //www.jpl.nasa. gov/radioastronomy/

X-BAND OBSERVATIONAL FUNCTIONAL BLOCK DIAGRAM

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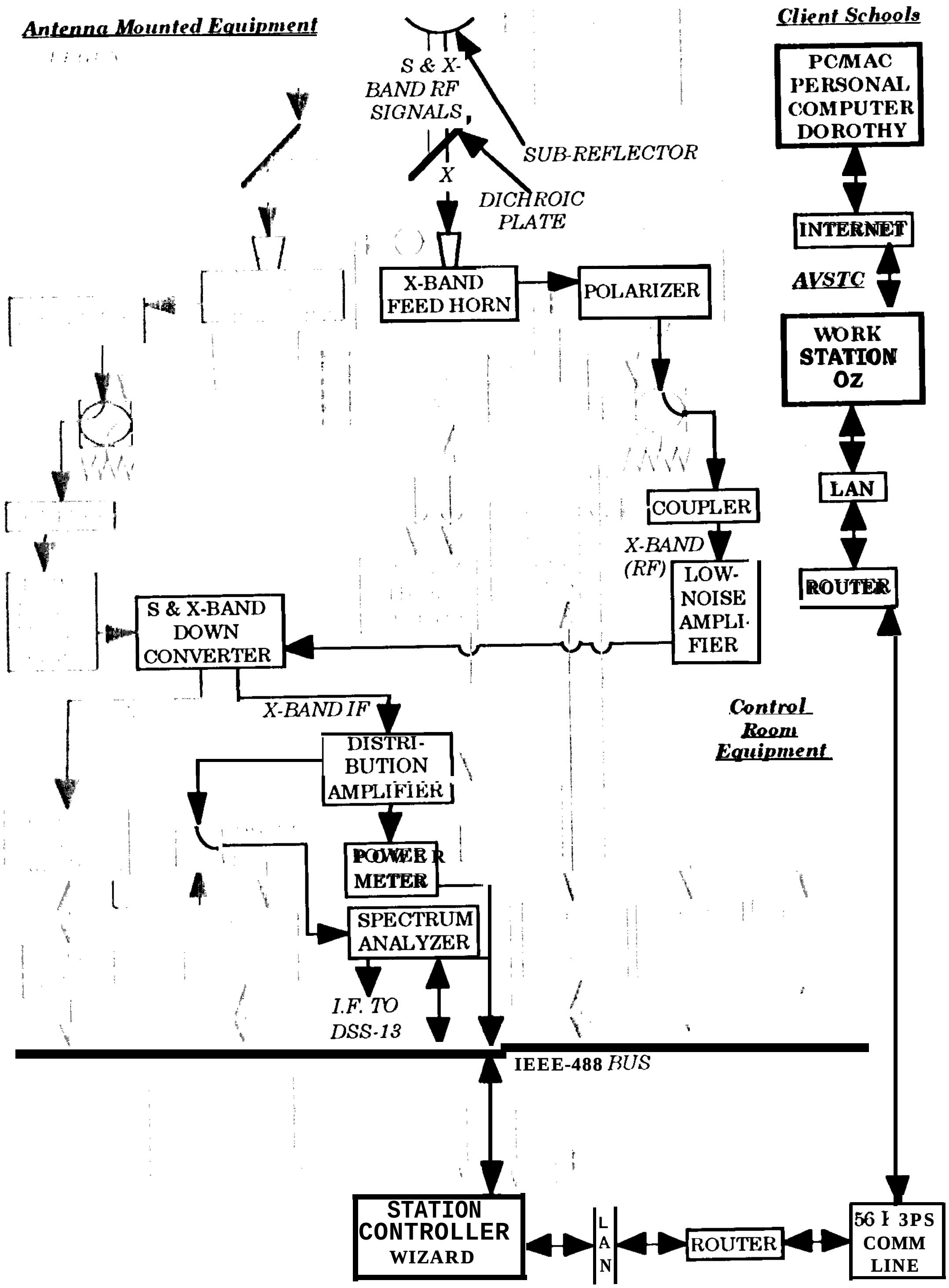


During this discussion keep in mind that X-band RF (Radio Frequency) energy is a higher frequency (shorter wavelength) than S-band RF energy (longer wavelength).

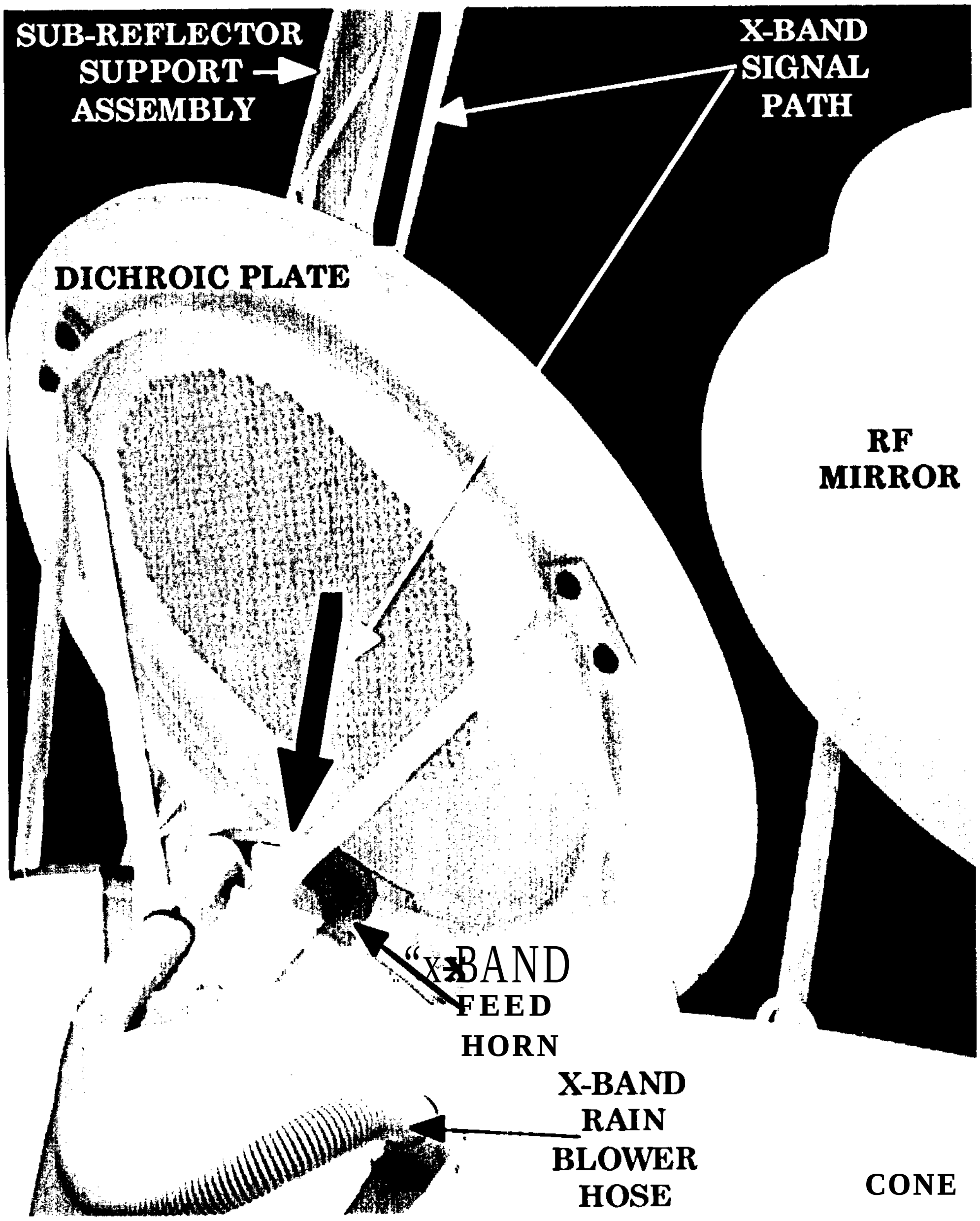
X-band RF electromagnetic energy arriving at the GAVRT antenna primary reflector (a parabolic section) is reflected to:

1. The sub-reflector (a hyperbolic section, also known as the secondary reflector), which reflects the signal onto,

2. The dichroic plate, which is transparent to X-band, and passes the signal past the X-band rain blower to the X-band feed horn.

NOTE

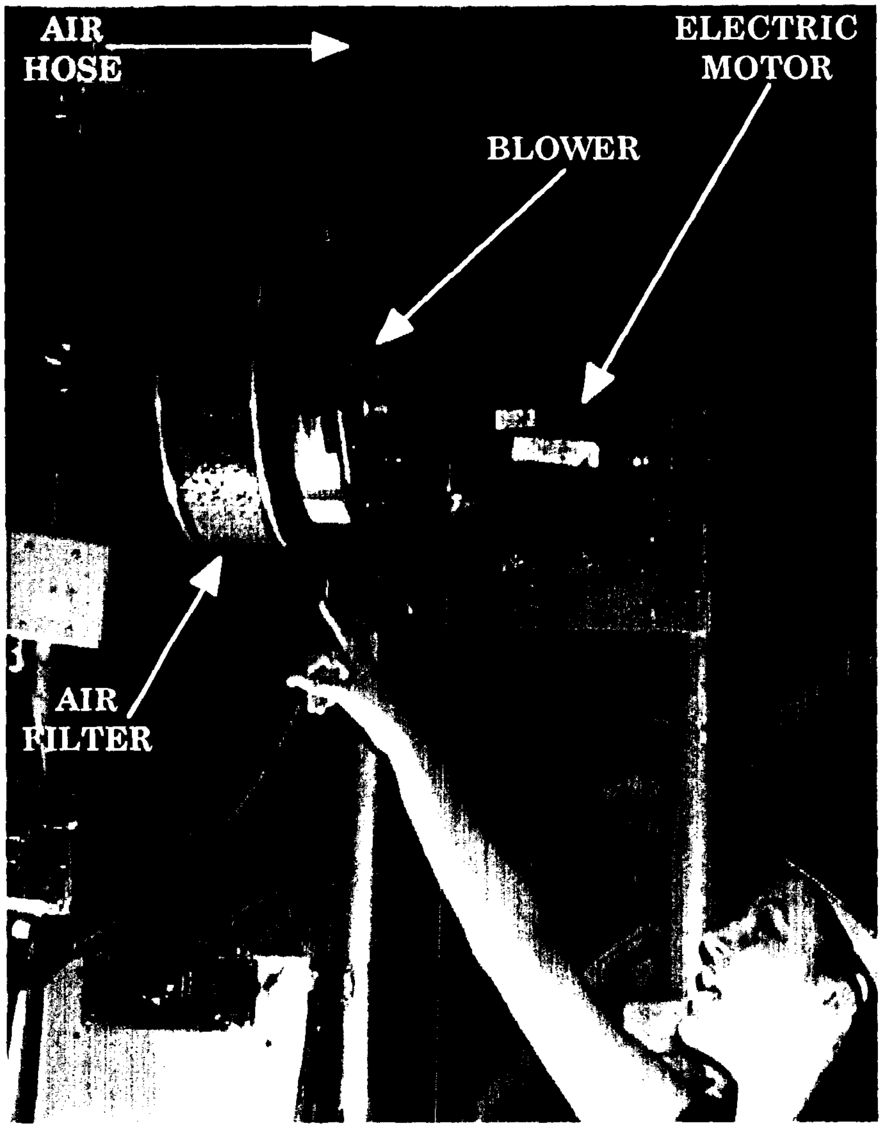
The dichroic plate works on the same principal as the window on the door of a microwave oven. The window passes light frequency electromagnetic energy through the holes of the door to allow you to see inside the oven (see following diagram). However, the longer radio (microwave) frequencies produced by the heating element of the oven are blocked by the window, confining the microwave energy to the oven. The GAVRT dichroic plate holes pass X-band wavelengths, and reflects S-band wavelengths of electromagnetic energy.



X-BAND FEED

NOTE

Water drops on the feed horn cover add very significantly to the total noise seen by the system. The X-band rain blower is a blower inside of the antenna cone that maybe turned on when it rains. The rain blower pumps filtered air across the plastic cover of the X-band feed horn to remove water drops. The X-band rain blower is most effective in a mist or light rain, and is nearly totally ineffective in a heavy rain. Fortunately, the Goldstone area seldom gets heavy rain. The S-band feed horn does not have a rain blower because S-bands lower frequency (longer wavelength) is not nearly as effected by rain.



X-BAND RAIN BLOWER

3. The X-band feed horn where it is focused and passed,

4. Through the X-band polarizer, which adjusts the polarization to that of the RF source, and is passed,

X-BAND FEED ASSEMBLY

5. Through the X-band microwave switch to,

6. The coupler, which allows test signals to be injected into the system during calibration procedures, and to,

7. The X-band Low Noise Amplifier (LNA), which amplifies the signal level with minimal noise addition, and to,

8. The S & X-band down converter, which translates the X-band signal into a proportional IF (Intermediate Frequency, in this case a few megahertz), and to,

9. The X-band distribution amplifier, which maintains the proper signal level, and to,

   A. The S & X-band selector switch, which routes the signal to the spectrum analyzer, which formats and displays amplitude verses frequency plots of the received signal and forwards this data to the station controller "Wizard".

   B. The X-band power meter which measures the power of the signal and forwards a digital expression of that measurement across the IEEE-488 bus to:

NOTE

An "1. F. To DSS- 13' **output** of the spectrum analyzer has been provided to allow GAVRT spectrum analyzer data to be sent to DSS-13 (Deep Space Station-13, Venus Site) for processing. This capability may be implemented in the future.

10. Station controller wizard, which forwards signal power verses time data across,

12. The LAN (Local [to Goldstone] Area Network), and through,

13. The router at GAVRT-Goldstone, and through,

14. The 56 kbps Comm line, and through,

15. The router at the AVSTC, and across,

16. The LAN at the AVSTC, to,

17. Workstation "OZ", at the AVSTC.

18. Users at PC/Mac personal computer "Dorothy" at the client schools may download S-band data by using FTP (File Transfer Protocol) techniques causing this data to,

19. To be sent from the Workstation "OZ", at the AVSTC

20. Across the internet,

21. To the PC/Mac personal computer "Dorothy" for display/recording.

QUIZ

1. X-band RF (Radio Frequency) energy is a ______________________ ____________________ (shorter wavelength) than S-band RF energy (longer wavelength). Answer: Higher frequency.

2. The X-band rain blower... is nearly totally ________________________ in a heavy rain. Answer: Ineffective.

GAVRT ANTENNA BITS AND PIECES

Learning Objectives for this Section

Completion of this section will enable learners to:

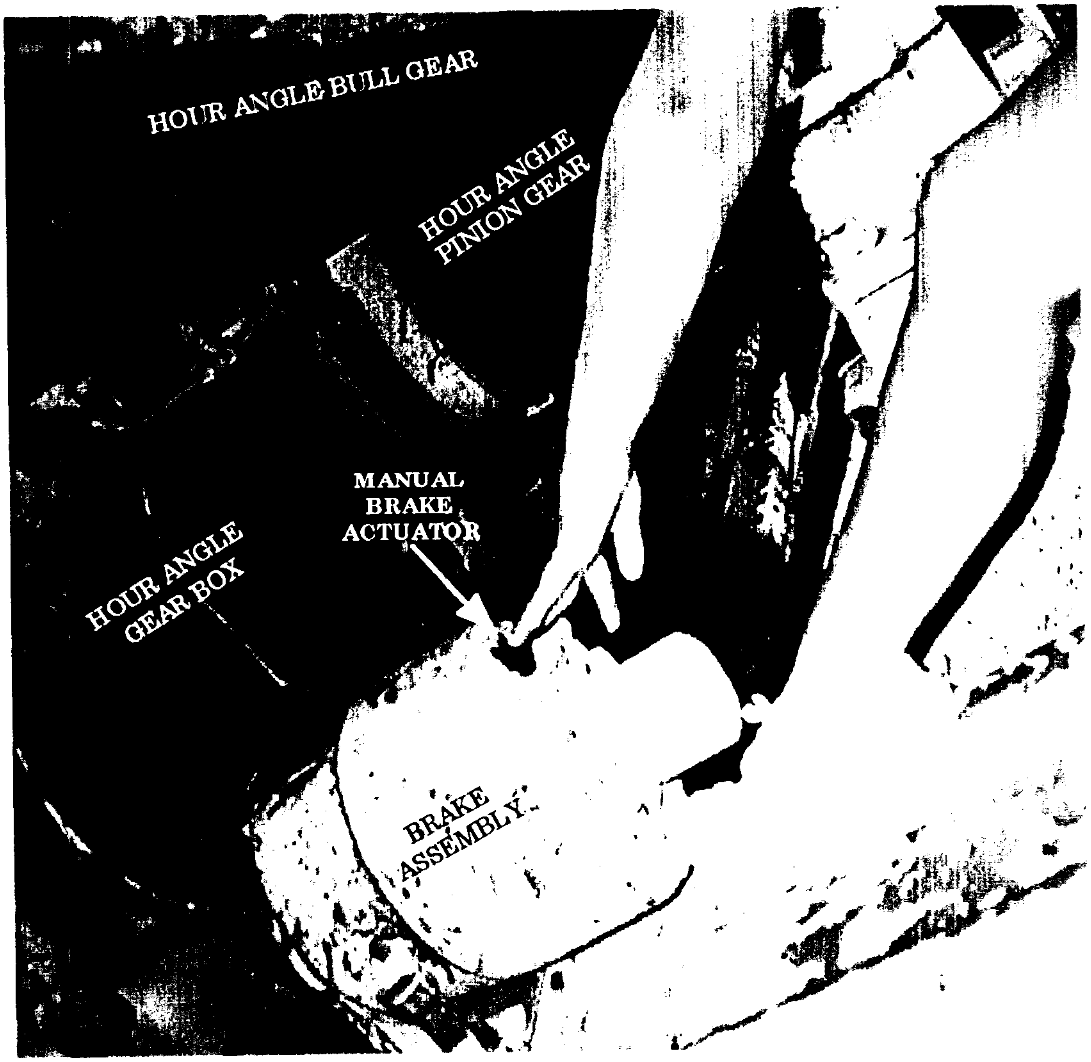
- Describe the function of the brakes
- Describe the torque multiplication ratio of the gearboxes
- Each axis has two motor-gear box sets
- Define the *astronomical horizon*
- Define *elevation*
- Define *Zenith*
- Define *Nadir*
- Define *Azimuth*
- Define *local* ***horizon***
- Explain why, given only one GAVRT antenna pointing coordinate, it is not possible to determine if that coordinate is within the GAVRT antenna limit contour
- Explain the function of the antenna limit switches
- Quantify *sidereal rate*
- Identify the two basic reference books of astronomical coordinates

Introduction

To ensure safe operation of the GAVRT antenna it is necessary to have a sense of what the equipment is like that moves the antenna, indicates antenna pointing angles, and constrains the movements of the antenna. This section of the module discusses these issues in more detail.

Brakes

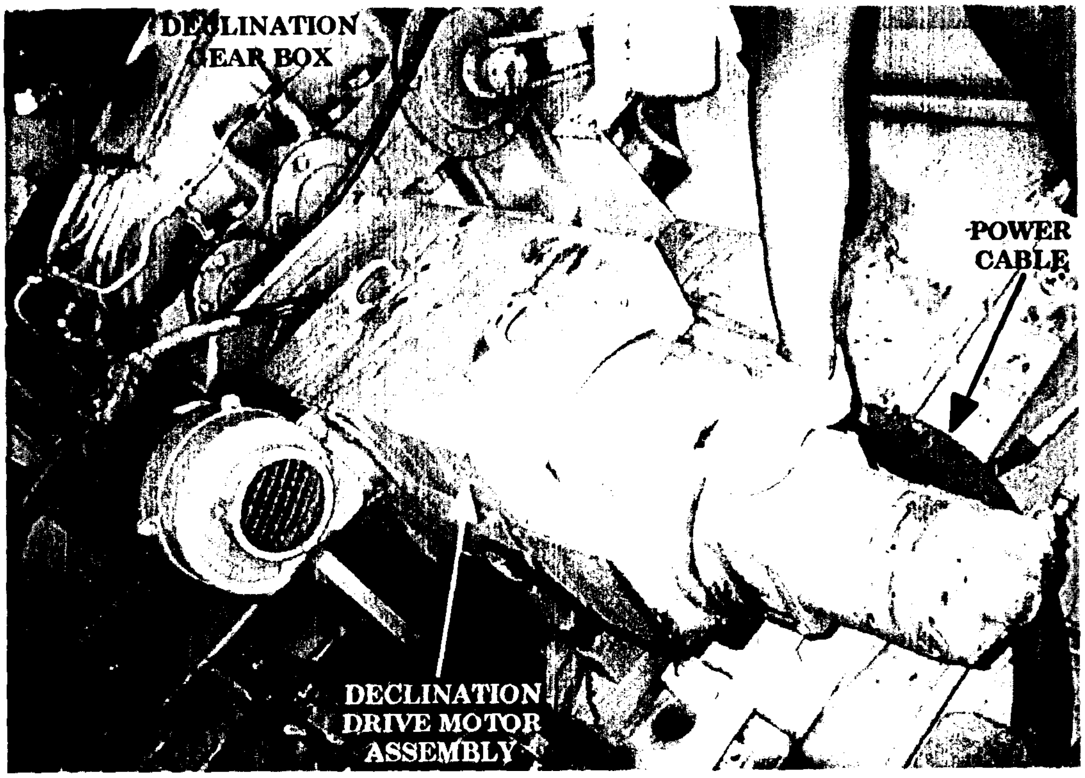
Each of the four gearbox sets have an electrical brake assembly attached to the input shaft. These brake assemblies are surprisingly small given that they must stop tons of rotating steel nearly instantly. The GAVRT brakes can be small because their braking force is multiplied by 5,000: 1 through the gearboxes. The antenna brakes are usually operated electrically by remote control, but can be operated manually by way of an actuator on the brake assembly.



BRAKE ASSEMBLY

Drive Motors

As with the brakes, the drive motors are also surprisingly small given the work they must perform. Again, because their torque is multiplied by 5,000: 1 through the gearboxes, they can be made quite small.

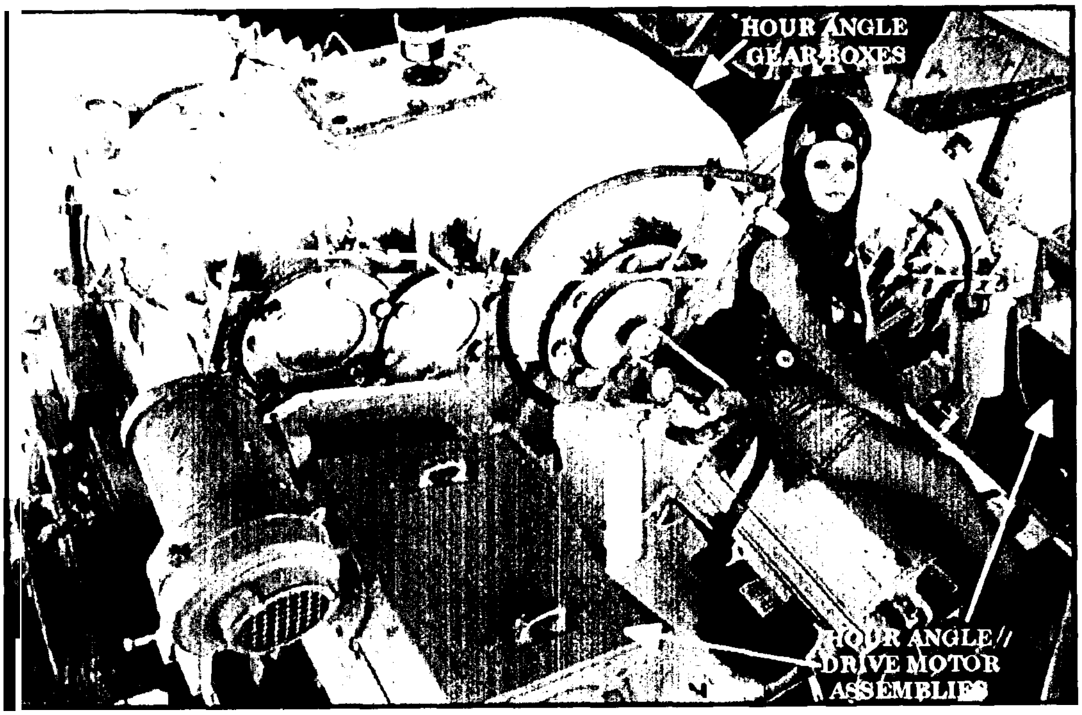


DECLINATION DRIVE MOTOR ASSEMBLY

Antenna Drive Gear Boxes

The GAVRT antenna has two antenna drive gear boxes for each axis of movement. Each gearbox provides its associated drive motor a mechanical advantage of 5,000: 1. Gearboxes with large mechanical advantages intrinsically have a lot of backlash (play in the contact of each gear set within the gearbox). To prevent the antenna from rocking back and forth in this play zone, especially when the antenna changes direction, each axis is fitted with two identical gearboxes. The electrical command signals to the drive motors are automatically adjusted to cause the two pinion gears on each axis to <u>slightly</u> drive against each other. This maintains a tension between the two pinion gears through the bull gear on each axis, removing the backlash.

HOUR ANGLE BULL GEAR AND PINION GEARS



HOUR ANGLE GEAR BOXES

QUIZ

1. The electrical command signals to the drive motors are automatically adjusted to cause the two pinion gears on each axis to slightly drive __________ each other. Answer: Against.

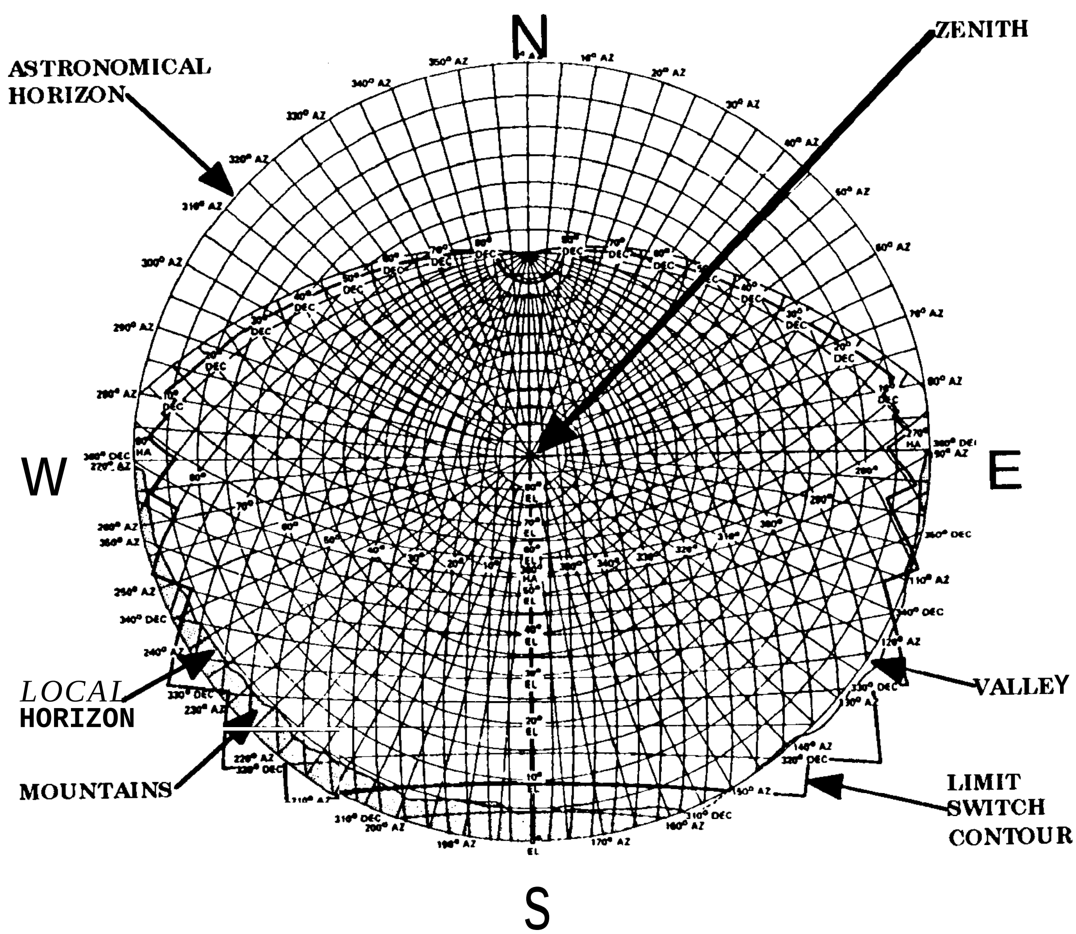
Pointing Limit Contour

In the calculation of rise/set times there are three constraints that may limit GAVRT pointing the astronomical horizon, the local horizon at the GAVRT, or the antenna limit switches.

The *astronomical horizon is* **an** imaginary plane projected outward from the antenna perpendicular to the Zenith-Nadir line (an im aginary line between straight up and straight down). This p] ane extends outward in all directions without regard for terrain. If the antenna were at sea the astronomical horizon would represent the minimum useful elevation angle of pointing, and the astronomical horizon would be the same as the local horizon.

Elevation is defined as degrees measured upward from the astronomical horizon. *Azimuth* is defined as degrees measured eastward from north, and Zenith is defined toward straight up, as Nadir is toward straight down.

The *local horizon* is irregular and extends out from the antenna to the lowest elevation angle for any azimuth angle considered. The local horizon takes into account mountains and valleys. Mountains increase the minimum elevation angle of antenna pointing at any given azimuth, while valleys decrease the minimum elevation angle of antenna pointing at any given azimuth.

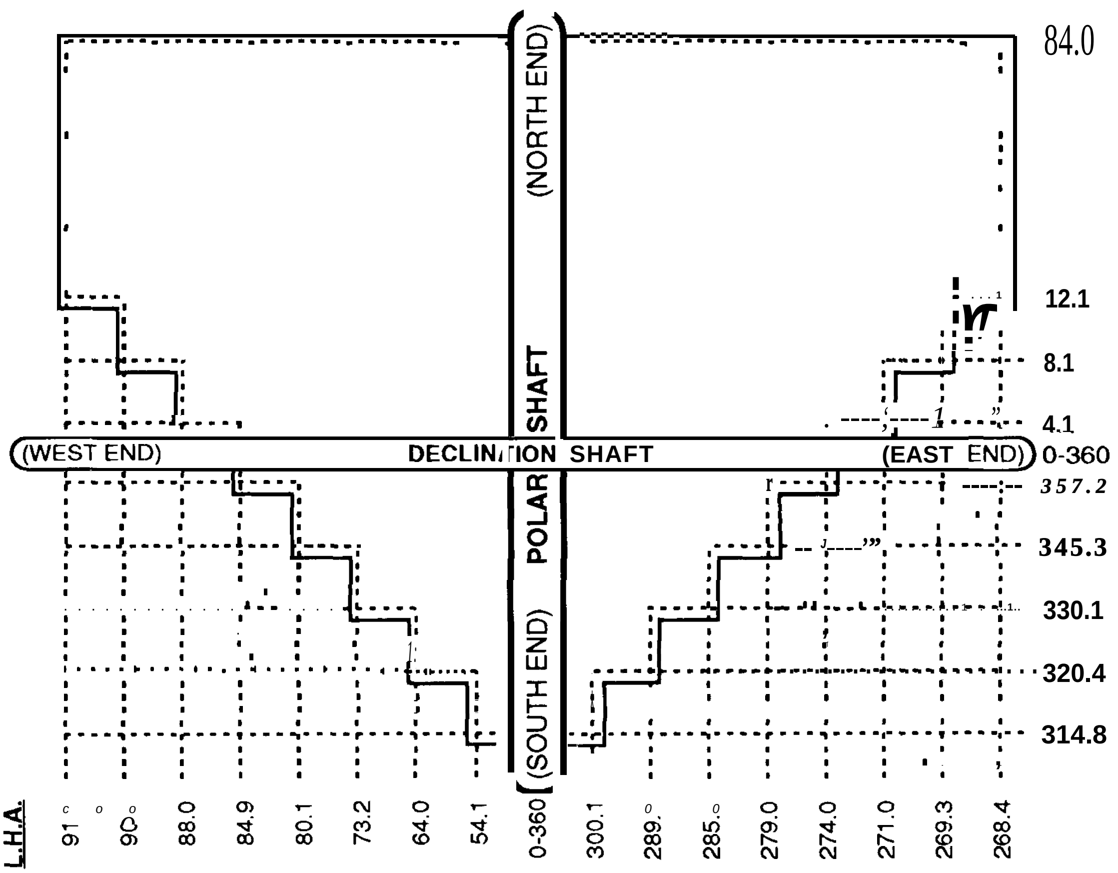


GAVRT ANTENNA HORIZON MASK

The Horizon Mask presented above overlays declination and GAVRT local hour angle coordinates upon azimuth-elevation coordinates. The GAVRT antenna limit switch contour is also displayed on this diagram.

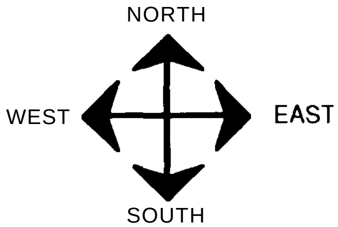
The concentric circles centered on Zenith represent elevation angles, and the largest of these circles represents the astronomical horizon at 0° elevation. The radial lines (spokes) emitting from Zenith represent azimuth angles. The irregular line that roughly follows the astronomical horizon is the local horizon, which shows both mountains and valleys. The curvilinear two-coordinate overlay represents the local hour angle and declination grid. The notched appearance of the southern boundary of the Local Hour Angle and declination grid is caused by the limit switch contour (see the following diagram).

GAVRT ANTENNA LIMIT CONTOUR



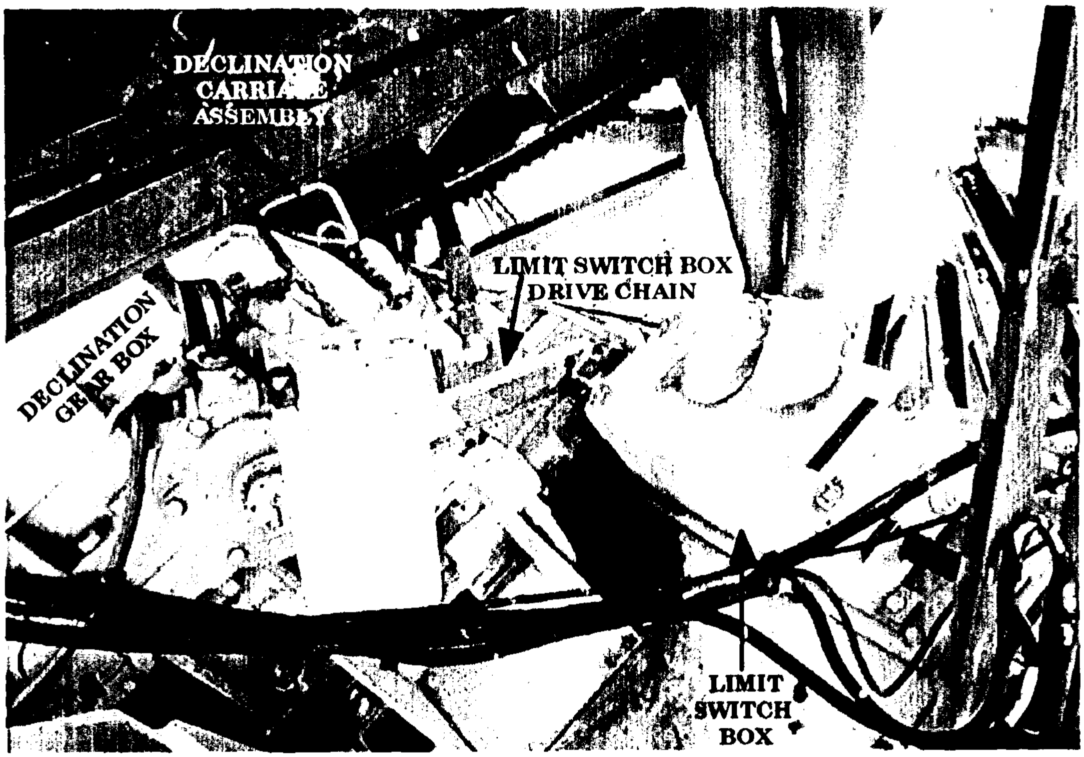
NOTES

1. **LHA & DEC Encoders actually read from O-359.998 degrees**
2. **Pre Limits = ----------------**
3. **Final Limits = ————————**



A plot of the GAVRT antenna limit contour is shown above. Notice that given only one axis angle, either local hour angle or declination, it is not possible to determine if that coordinate is within the GAVRT antenna limit contour. This is true because the GAVRT limit contour is the product of two coordinates, local hour angle and declination. Both local hour angle and declination axis angles must be know to determine if the GAVRT antenna can point to a given coordinate set at a given time.

The ***Antenna Limit Switches*** automatically interrupt antenna operations when the antenna angle is approaching a permanent obstacle, either the ground or part of the antenna's supporting structure. If the declination and local hour angles of an RF source are known, this chart maybe used to determine the rise/set Goldstone local hour angles. Rise/set times for the GAVRT antenna may be calculated using the "The Astronomical Almanac" and/or the "Nautical Almanac", to determine at what time an RF source at that declination angle will move inside (rise)/outside (set) of the GAVRT antenna limit contour.



DECLINATION LIMIT SWITCH BOX

There are a set of pre-limit and a set of final-limit switches for each axis of the GAVRT antenna. As the antenna rotates, the gear box rotates, and through a drive chain, rotates a cam shaft inside of the limit switch box. As limit angles are approached, a cam lobe actuates one of the microswitches within the limit switch box, and sends this new switch state to a logic circuit.

Both axis are concurrently and constantly sending switch state signals to the logic circuit. Specific combinations of hour angle and declination antenna positions are required to create an out-of-limits state. When the logic circuit sees an out-of-limits condition, it automatically interrupts the antenna drive signal and applies the brakes.

Notice that the limit switch logic control s are completely independent from the angle encoders. This was done to ensure that in the event of an encoder failure, the limit switches would still function.

QUIZ

1. The *astronomical horizon...* extends outward in all directions without regard for ______________. *Answer.* **Terrain**

2. The local horizon takes into account ____________________ and valleys. **Answer: Mountains.**

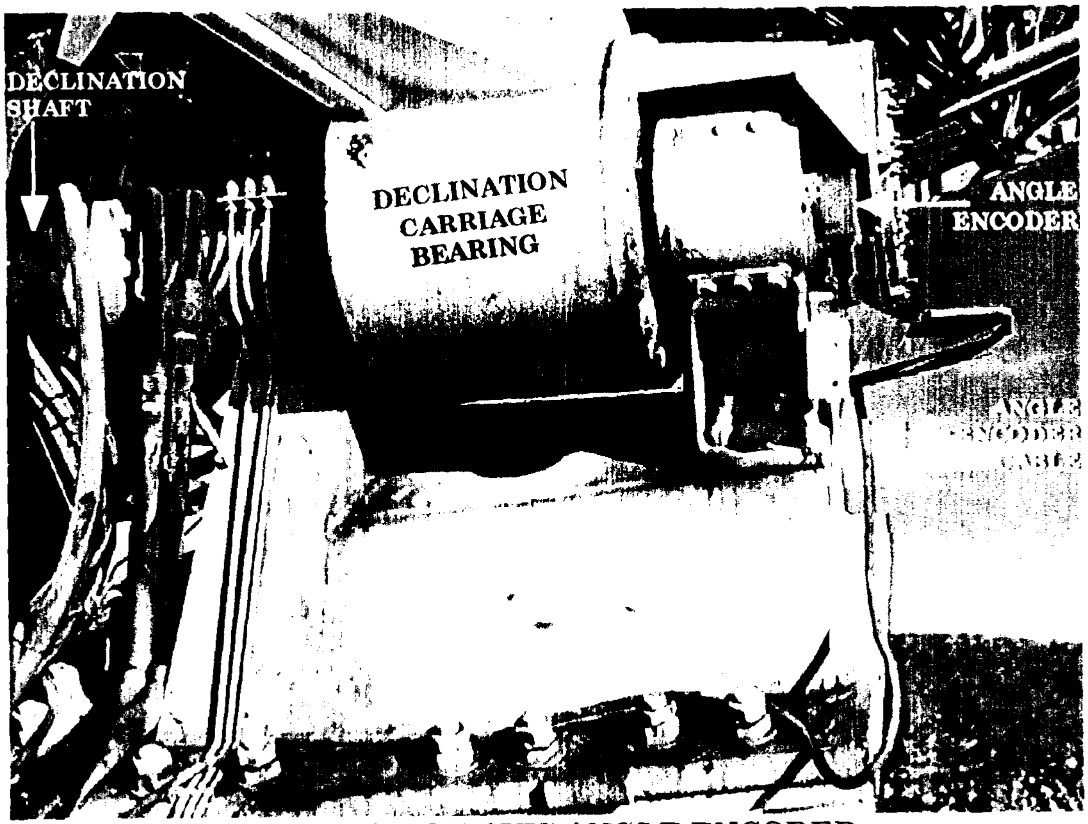
3. The GAVRT limit contour is the product of two coordinates, ____ **Answer: Local Hour Angle and Declination.**

4. Specific ____________________. of hour angle and declination antenna positions are required to create an out-of-limits state. **Answer: Combinations.**

5. ...limit switch logic controls are completely independent from the ________________________.... **Answer: Angle encoders.**

Angle Encoders

The GAVRT antenna has one angle encoder for each axis of movement. The encoders translate local hour angle and declination shaft angles into proportional electrical signals. These encoders are configured to express degrees from OOO.OOO° to 360.000°, to a resolution of 0.002°.



DECLINATION AXIS ANGLE ENCODER

QUIZ

1. The encoders translate local hour angle and declination shaft angles into ______________________ electrical signals. Answer: **Proportional.**

2. These encoders are configured to express degrees from OOO.OOO° to 360.000°, to a resolution of ________. **Answer:** 0.002".

Horizon Mask

During normal operations the GAVRT antenna pointing angles are generated by the software, and users of the instrument do not have to calculate these angles. However, an understanding of these angles, and their limitations, will make mission planning easier, and will increases the user's awareness of when and for how long an RF source will viewable at the GAVRT antenna. This knowledge is essential if manually calculating RF source rise and set times.

Two basic reference books provide the coordinates for many common astronomical bodies:

1. "The Astronomical Almanac", ISBN O-11-886505-6, current year

2. "Nautical Almanac", ISBN O-16-048667-X, current year

Both of these documents are published in August of each year for the following year, are available inexpensively in most bookstores, and while not required, they are recommended reading for client school users of the GAVRT system. They contain many tables of source positions, and the formulas required for translating source positions on the celestial sphere into local coordinates for any location on earth, for any time of day, on any day of the year.

The longitude and latitude of the GAVRT antenna must be know to use these documents to solve antenna pointing problems. The GAVRT antenna is located at

Longitude = 116.805° west

Latitude = 35.300° north

To use these tables Sidereal *Rate* must also be know, which is: 0.2500/minute, or 150/hour. And, it is helpful to know that the First Point of Aries = O.O° Right Ascension = O.O° Sidereal Hour Angle.

QUIZ

1. Sidereal Rate... is: ___________ /minute. **Answer**: *0.250°*.

2. .. the First Point of Aries = o Right Ascension. **Answer**: 0.0.

APPENDIX A

BIBLIOGRAPHY

PURPOSE OF THIS APPENDIX

The purpose of this appendix is to provide a list of the references consulted in the development of this module.

Astronomical Almanac for the Year **1997,** *The;* Superintendent of Documents, U. S. Government Printing Office, Washington D. C., 20402-9328

Deep Space Telecommunications Systems Engineering; 1983; Joseph H. Yuen; Plenum Press; New York & London; ISBN 0-306-41489-9

Dictionary of Electrical and Electronics Terms, IEEE Standard (ANSI/IEEE Std. 100- 1984); third edition, 1984; Wiley -Interscience; Library of Congress Number 84-081283

Dictionary of Scientific and Technical Terns, McGraw Hill; third edition, 1984; McGraw-Hill Book Co., New York, St. Louis, San Francisco; ISBN 0-07-045269-5

Exploration of the Universe, Abell's; seventh edition; 1995; D. Morrison, S. Wolf, A. Fraknoi; Saunders College Publishing ISBN 0-03-001034-9

Nautical Almanac for the Year **1997,** *The*; Superintendent of Documents, U. S. Government Printing office, Washington D. C., 20402-9328

Reference for Deep Space Stations Horizon & Transmitter Masks; Bendix Field Engineering Corporation, Operations Engineering & Analysis Dept., 24 February 1992, Jet Propulsion Laboratory

APPENDIX B

GAVRT SYSTEM CHARACTERISTICS

PURPOSE OF THIS APPENDIX

The purpose of this appendix is to provide a listing of the major GAVRT system specifications or characteristics.

PARAMETER	VALUE	REMARKS
Gain (dBi)		At gain set point
S-band	56.2 dBi	
X-band	66.2 dBi	
Beamwidth (deg)		Half-power angular width
S-band	0.31 +/- 0.02	
X-band	0.075 +/- 0.005	
Polarization		
S-band	Right circular polarization (RCP), or left circular Polarization (LCP)	One polarization at a time, remotely selected
X-band	Right circular polarization (RCP), or left circular polarization (LCP)	One polarization at a time, remotely selected

Ellipticity (db)		Peak-to-peak axial ratio
S-band	*0.7 +/- 0.3*	
X-band	*0.7 +/- 0.3*	
Receiver		
Total system noise **temperature (Kelvin)**		For cold sky near zenith
S-band	68	
X-band	120	

APPENDIX C

HISTORY OF GOLDSTONE

PURPOSE OF THIS APPENDIX

The purpose of this appendix is to provide a history of the region, explain why Goldstone is located where it is, briefly describe of the climate at Goldstone, and summarize the history of the GAVRT project.

...IN THE BEGINNING

The Mojave Desert of California is a high desert that is between 2,500 and 3,500 feet elevation above sea level, with a few mountain peaks reaching to 5,000 feet. This region is characterized by a severe climate. Pacific storms from the Gulf of Alaska sweep southeastward through the region in the winter, but much of their moisture is rung out before they reach the Mojave Desert when these storms squeeze across the coast ranges and the Sierra Nevada mountains to the north and west. The meandering Mojave River bisects the Mojave Desert and terminates at Soda Dry Lake (a sink) near Baker, California, although it only flows that far during extreme flooding which is very rare. Night time winter temperatures commonly drop well below freezing at the higher elevations. Occasionally a winter storm will bring with it weather cold enough to dust the desert floor with snow. Spring on the Mojave Desert is characterized by very strong winds associated with the passage of arctic weather fronts, and in wet years, by spectacular displays of wild flowers. Sub-tropical flows from Mexico bring rare summer thunderstorms and flash floods to specific locations in the region. Cloudless summer daytime temperatures in excess of 110 degrees are common. Fall is perhaps the most temperate season on the Mojave with clear skies, mild temperatures, and little wind.

The Mojave Desert region has been inhabited intermittently by pre-Columbian peoples for nearly as long as men have been on the North American continent, perhaps 12,000 years. The key to human population of this harsh region is water. The Mojave Desert is devoid of standing water except for dry lakes (sinks or playas) that remain wet for a few weeks after a heavy storm, but are very mineralized and brackish. There are a few springs scattered across the desert. But without a guide or a good map they are very difficult to locate.

Mojave and Shoshone Indians very sparsely populated the Goldstone region of the Mojave Desert before it was first explored by the European men. Their petroglyphs, pottery shards, and arrowheads can still be located in the area, and on the GDSCC (Goldstone Deep Space Communications Complex). For more information on the Mojave Desert see the Digital Desert at URL:

http: //www.ceol.com/digitaldesert/

DESERT WATER

The only river in the Mojave Desert is the Mojave River. The Mojave River originates on the north slopes of the San Bernardino Mountains and meanders generally northward through Barstow (about 30 air miles south of Goldstone), where it turns generally eastward on its way to Soda Dry Lake (sink or playa) 50 air miles east of Barstow. The Mojave River is located in the Great Basin geological province and none of its few rivers return water directly to the ocean). In its untamed state, the Mojave River often ran below ground for miles, surfacing here and there, and then disappearing again under the sand, only to resurface again further downstream. The Mojave River now has a flood control dam where it emerges from the San Bernardino Mountains onto the desert floor. During floods this desert waterway became a raging torrent tens of feet deep and hundreds of feet across, for a few hours at a time, a few times a century. And just as quickly the Mojave dried-up, usually for years at a time at a given location. As intermittent as the Mojave River and its associate d aquifers were, they were the only semi-reliable surface water source available to the region.

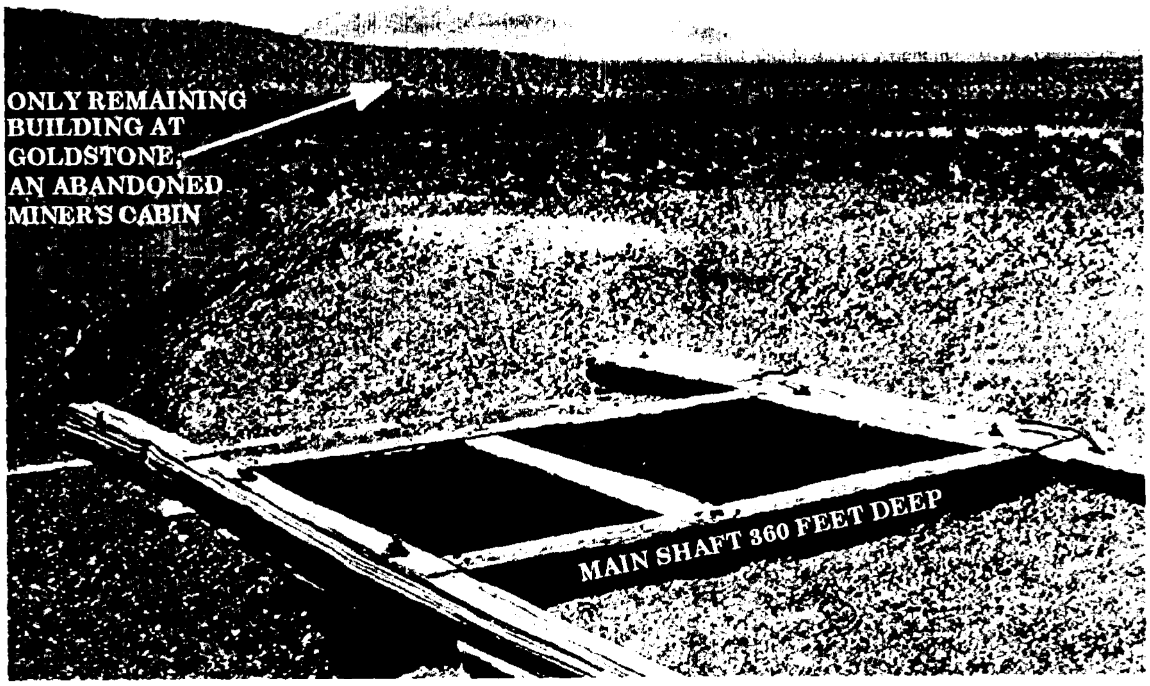
Because of the availability of water the Mojave River route was used by the first explorers in the region in the early nineteenth century. The early explorers' use of this route was followed by pioneers, rushing to California's mother lode and to the fertile valleys of California. The town of Barstow was founded as a watering stop for the railroad, and now is a terminus for the Burlington Northern & Santa Fe, and Union Pacific railroads, including tracks that lead to Las Vegas, Flagstaff, Los Angeles, and toward California's Central Valley, via Bakersfield.

In the early 1970's the Santa Fe railroad constructed a large automated rail classification yard in Barstow to reduce traffic on its congested Los Angeles rail lines. Barstow also is a junction for I-15 to Las Vegas and toward Los Angeles; 1-40, to Flagstaff state highways 58 to Bakersfield and 247 to Lucerne Valley; and has several large truck stops and commercial trucking terminals. Several commercial power transmission lines connecting Los Angeles with Hoover Dam pass near Barstow, and also tie into the solar generating plant in Yermo (just outside of Barstow), and into the commercial power grid. Transcontinental microwave links also pass through the Barstow area, as does a major petroleum pipeline connecting Las Vegas with oil terminals and refineries in San Pedro (part of Los Angeles). The military is well-represented in the area with the U. S. Army's National Training Center at Ft. Irwin, and the U. S. Marine Corps Supply Center in Yermo. Federal, state, county, and local law enforcement authorities are also hubbed in Barstow. Barstow is the closest town to Goldstone and is also where most GDSCC personnel now live.

EUREKA!

Gold was first discovered on what is now the Goldstone complex at Leach Lake, a tiny dry lake about a mile south of the Goldstone's Deep Space Station- 14. Although not much came of this mining frontier discovery.

In 1910 placer and lode gold were discovered at the Wide awake mining camp, approximately 6 air miles south of Leach Lake at what is now known as the ghost town of Goldstone. Located at an elevation of 3,300 feet above sea level, activity at the camp picked up until in 1915 when a rush was on, and Goldstone had a population of 150 residents, nine tent-and-frame houses (rag-town architecture), and a hotel/boarding house that could sleep 25 and feed 100 miners. By 1916 substantial mining, including the operation of a ball mill, had begun and the main shaft was down 20] feet. In 1917 a post office was opened in the then brand new Goldstone Store. But by 1918 the value of the Goldstone ore was in serious decline. In August of that year the post office closed and from then on the mine and town of Goldstone were sustained mostly by hope.



GOLDSTONE MINE AND GHOST TOWN

From 1918 until present Goldstone has been intermittently mined. During this period several companies have sporadically tried and failed to sustain the Goldstone mining operations. By 1931 the main vertical shaft was down 300 feet, with several side drifts, and was eventually sunk to a depth of 360 feet. During WW II there was a ban on gold mining manpower and the area became all but deserted (no pun intended). The high price of scrap metal during the war motivated scavengers to strip most things metal from Goldstone. Without metal, desert mines become holes in the ground, lined with rotting shoring beams. However, the assessment work on several of the claims at Goldstone is still maintained.

TECHNOLOGY IN THE MOJAVE DESERT

World War H brought a great increase in military activity to the Mojave Desert. The U. S. Air Force began operations at Muroc Dry Lake (now Edwards Air Force Base), while the U. S. Navy began operations at what is now the Navel Weapons Center--China Lake. The U. S. Marine Corps Supply Center in Barstow was constructed in Yermo (adjacent to Barstow), and Ft. Irwin (now also know as the U. S. Army's National Training Center) was constructed forty miles north of Barstow, eight miles from the Goldstone Complex.

In the late 1950's JPL (Jet Propulsion Laboratory) sponsorship was transferred from the U. S. Army to NASA (National Aeronautics and Space Administration) when the modern NASA was formed. JPL began looking for a location on which to construct the tracking complex that would be needed to support the exploration of the solar system. After surveying several locations in the western United States, a small portion of the U. S. Army's Ft. Irwin was selected, and named Goldstone after the ghost town and mine that were just outside the boundary of the proposed complex, and after the largest of several dry lakes on the proposed tracking complex's reservation.

DEEP SPACE TRACKING–THE EARLY YEARS

In 1961 the first antenna at the newly created GDSCC (Goldstone Deep Space Communications Complex) was constructed approximately 200 feet southeast of where the GAVRT (Goldstone-Apple Valley Radio Telescope) is currently located at the Echo Site. Control room, engineering, administrative, cafeteria, maintenance, supply, and emergency power facilities and a bunkhouse were also constructed at the Echo Site during this time frame. This first Echo Site antenna was a 26 meter diameter, AZ-EL (azimuth-elevation) mount, fully steerable, L-band radio frequency structure.

In the early 1960's, the advent of the Apollo program to put a man on the moon created new requirements for the unmanned exploration of the moon. In particular, a highly detailed map of the moon was needed to support the selection of suitable landing sites, and the characteristics of the lunar surface had to be better understood to support the engineering of a lunar lander, that could safely land on the then unknown lunar surface.

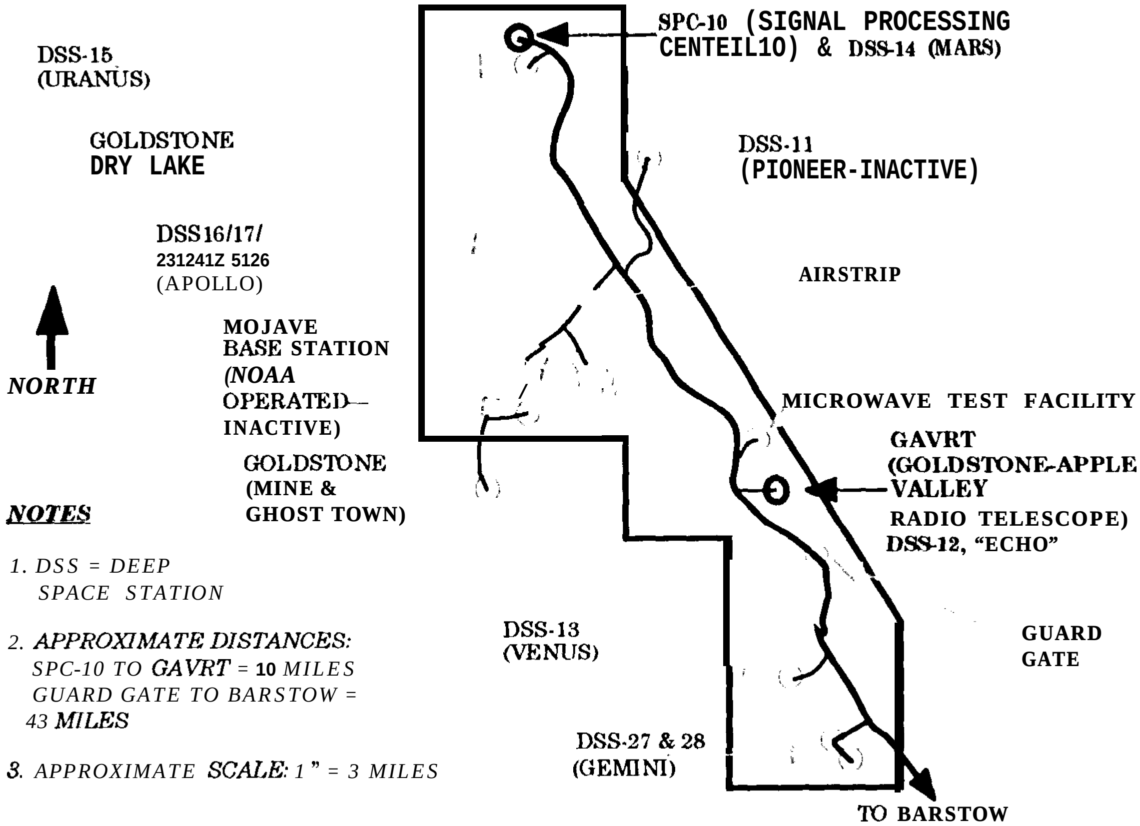
Lunar Orbiter project consisted of a series of spacecraft flown into lunar orbit that mapped 95% of the moon's surface in great detail. Concurrently, the Surveyor missions were landing spacecraft on, and measuring and photographing the surface of the moon. These requirements, and requirements to explore the solar system, provided the impetus for the creation of JPL's DSN (Deep Space Network). The DSN is a network of deep space antennas that provide around-the-clock tracking support of spacecraft, at lunar distances and beyond, via three complexes of tracking stations located approximately 120 degrees of longitude apart near Canberrra, Australia, Madrid, Spain, and Goldstone, USA.

To receive the RF (radio frequency) signals from spacecraft at deep space distances new tracking stations had to be designed, constructed, and made operational. DSS- 11 (Deep Space Station-11, Pioneer Site) was constructed as the first DSN (Deep Space Network) 26 meter diameter, HA-DEC (hour-angle--declination) mount, S-band radio frequency antenna. DSS- 11 was the engineering prototype for the 26 meter HA-DEC antennas of the DSN, including DSS- 12 (now the GAVRT), but it was also subsequently used to track the Surveyor mission to the Moon and many other spacecraft.

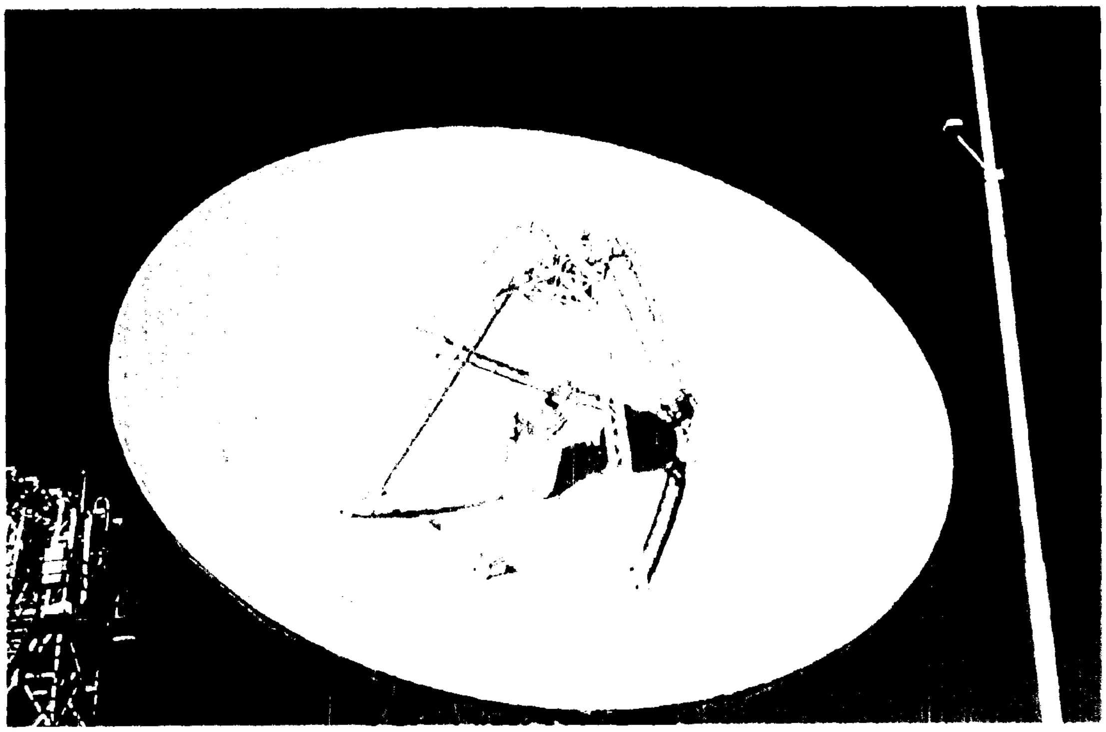
BIRTH OF THE GOLDSTONE-APPLE VALLEY RADIO TELESCOPE

In 1964, DSS- 12's 26 meter, S-band, hour angle-declination antenna was constructed at the Echo Site at Goldstone. That structure is the basis for the current GAVRT (Goldstone-Apple Valley Radio Telescope) antenna, and was used initially to track to the Lunar Orbiter missions to the moon, and subsequently Pioneer, Marineer, and many other deep space spacecraft exploring the solar system.

GOLDSTONE DEEP SPACE COMMUNICATIONS COMPLEX MAP



Once DSS- 12 was operational, the original Echo Site 26 meter AZ-EL (azimuth-elevation) was jacked up, put on a sled, and drug several miles across the desert by a tractor to its current location at Goldstone's Venus Site, where it resides today as a research and development antenna.



GAVRT ANTENNA IN ACTION

Between 1964 and 1996 many updates and upgrades were made to the DSS-12 antenna. All antenna cabling was replaced, the antenna bolts were replaced with titanium bolts, the entire antenna was lifted and placed on twelve-foot high concrete blocks to gain ground clearance for its enlarged 34 meter dish. X-band tracking capabilities were added to the original S-band cap abilities. Electronic tracking equipment in the control room has been continually automated, updated, and upgraded in response to ever more demanding mission support requirements for more sensitivity and higher data return rates, while lowering costs for each bit of science data delivered.

DSS-12 TO GAVRT CONVERSION

In 1996 plans were developed to convert DSS- 12 from a Deep Space Station into the GAVRT, and to transfer day-to-day operations from the Deep Space Network to the Apple Valley Science & Technology Center. The overall plan called for DSS- 12 to be converted from a spacecraft tracking system into a dedicated radio astronomy telescope system, to be operated by K-12 students designing their own observations within their science curricula, to be executed from personal computers at their home schools, via the internet and the AVSTC.

The hardware conversion mainly involved removal of the DSN transmitter (not required for most radio astronomy), replacement of the high maintenance cryogenically-cooled maser LNA's (low noise amplifiers) with solid state High Electron Mobility Transistor (HEMT) amplifier first stage amplifiers, and the removal of excess cables between the antenna and the on-site control room. Maintenance and repairs of the GAVRT continue to be performed by GDSCC personnel.

On the software side, existing DSN software was modified for its new role in support of a dedicated radio astronomy telescope.

The Apple Valley Unified School District established partnerships with JPL to convert, maintain, and repair the GAVRT; and with CalPoly-Pomona (California State Polytechnic University--Pomona [California]) to develop supporting K-12 science curricula, enabling the integration of GAVRT observations into educational science frameworks.

On October 30, 1996, NASA, JPL, and the Apple Valley Unified School District signed a Memorandum of Understanding describing the support agreement for the GAVRT (Goldstone-Apple Valley Radio Telescope).

STUDENTS OPERATE A REAL RADIO TELESCOPE– DOING REAL SCIENCE

In 1997 AVSTC operations came online allowing AVSTC volunteers to operate the GAVRT from Apple Valley, to oversee downstream client schools GAVRT operations, and to provide technical support to downstream users.

In October of 1997 access to the GAVRT by downstream schools via the internet was made operational with most supporting elements online.

APPENDIX D

ABOUT THIS MODULE

PURPOSE OF THIS APPENDIX

The purpose of this appendix is to describe how the text and images for this module were created, and to request feedback from users of this module.

LEARNING MODULE: NEEDS ANALYSIS, DESIGN, DEVELOPMENT, AND PRESENTATION

The learning standard for this module is completion of the module. Short quizzes are provided in the core sections of the module to reinforce the learning and to provide progress feedback to the learner.

This training was based on a training needs analysis of the AVSTC operator position at the AVSTC. All performance-related learning objectives were developed, and then linked to knowledge-oriented learning objectives. The knowledge-oriented objectives were developed from the performance -oriented objectives; based on inference, experience, and intuition. This analysis was documented and served as the technical foundation for designing and developing this learning module.

The original design (for the AVSTC Volunteer Operators) specified that this training would employ lecture-tour media, and included a climbing tour of the GAVRT antenna. Many of the photographs in this module are presented to offset the lack of a physical tour, and to provide learners a sense of the size and scale of the GAVRT antenna, since most learners will probably never actually see the GAVRT antenna.

After this module was presented to the operators in the lecture-tour medium, it was agreed that the module should be translated into a web-compatible medium; making it available to GAVRT client school ("Dorothy") users, and to anyone on the web who wants to learn how a radio telescope works.

This learning module employs a self-managed, self-paced, offline, on or off-screen instructional medium. This module may be used by downloading the .pdf file, and printing it or displaying it on your personal computer screen. The general design is based on a workbook format, within an Acrobat .pdf file. Acrobat was selected over HTML because of its ability to support high fidelity printouts of the module.

In October 1997, this learning module, and the image library created to support it were delivered to the AVSTC for sustaining maintenance. Since several GAVRT system enhancements are planned for the future, this module will be updated as required to keep pace with changing GAVRT system capabilities.

IMAGE RESOLUTION

One of the fundamental requirements for the design of this module was that it be made as inclusive as possible. That is, it should be accessible by the maximum number of people. Taken to its extremes, this requirement would prohibit any kind of electronic distribution because some client schools do not have personal computers, and many they do possess are slow, low-end systems.

Secondary requirements on the module to support slide shows, viewgraph presentations, and poster size photographs from these same images demanded high resolution original images.

A major question in the design of this module was, how much resolution should the photographic images contain? Byte-wise this module is composed of more than 99% images. Using the lowest resolution photographs, the complete module size would have been well under 1 mb, while embedding the highest resolution photographs would yield a module size of over 200 mb. To accommodate these conflicting requirements compromises had to be made, particularly in regard to image resolution. The decision was made to key the image resolutions to nominal laser printer resolutions, since it was understood that most schools would only need to print out the module once, and then duplicate as many paper copies as needed.

THE ORIGINAL IMAGE MEDIUM

Given these requirements and constraints, the 35 mm photographic format was selected as the original image medium for this module. Digital imaging systems were considered and rejected for two reasons: 1) Standards for digital imaging have yet to emerge, leaving the future of some digital imaging systems questionable at the moment; and 2) digital imaging systems that would satisfy all of the module's resolution requirements were prohibitively expensive (>$40K). Fine grained 35 mm film original materials can make sharp photographic posters up to approximately 30 X 40 inches, satisfying this module's most demanding resolution requirements.

The film selected was 35 mm Kodak Elite II, ASA 100, color transparency (slide) film. This film was selected for its fine grain, quick and easy processing (Kodak's E-6 process), and general availability.

All photographs were taken with a normal (50 mm) focal length lens. This means that neither telephoto (narrow view) or wide angle (wide view) lenses were used. Therefore, all images appear very much as they would to the naked eye, if the viewer were to position him/herself in the same position and view as the camera lens.

ELECTRONIC IMAGE MANIPULATION

After the film was processed (normal, E-6), the slides were reviewed, and the rejects were destroyed. The remaining slides were professionally scanned onto Kodak Photo CDs. Images on Kodak Photo CDs are viewable in 5 different sizes and resolutions: Each embedded photograph was created from the lowest resolution files available without degrading image quality when printed as .pdf files. Therefore, Acrobat Reader's zoom feature will only reveal some of the hidden details, because the image resolutions were constrained to the resolution of a laser printer to reduce file sizes and bandwidth requirements. Because of the low resolution of laser printers, the photographic images were made as large as possible, within the limits of the Microsoft Clipboard's 1 mb size limit (see last paragraph).

All of the photographs in this module were groomed from their raw state (as scanned onto the Kodak Photo CD) into how they appear in this module. All Kodak Photo CD images must be size/resolution-selected, cropped, re-sized, spotted, adjusted for brightness and contrast, and approximately half of these images need to be rotated 90 degrees in Adobe Photoshop to place the top of the image at the top of the Photoshop frame. If the image is to be captioned or annotated, it then needs to be placed in a Claris Draw file for these additions.

With the image now ready for presentation it is placed into a destination file, like Microsoft Word. To maintain cross-platform, cross application, compatibility, the MS Word file was then translated into a .pdf file by Adobe Acrobat. The Adobe Acrobat file was then placed on the AVSTC server for to downloading and use. The Acrobat format was selected over HTML because of the expectation that most users of this module will not have the computer access time required to complete this training on-screen, and will need to print it out for use off-screen.

FEEDBACK ABOUT THIS MODULE

As new capabilities are added to the GAVRT system and feedback is received from users of this module, this module will updated and/or upgraded as appropriate. Sustaining and improving the quality of this learning module in response to feedback from actual users of this module is an important goal of the GAVRT project. Please forward your comments about this module to:

Robert Mcleod
GAVRT Operations Manager
Apple Valley Science & Technology Center
P. O. Box 818
Apple Valley, CA 92307

Phone: 619-242-3514
Fax: 619-242-3783

Internet: bob_mcleod@eee.org

with a "cc" copy sent to:

George R. Stephan
Training Engineer
MS 230-303
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

Phone: 818-393-7916
Fax: 818-393-7844

Internet: george.r.stephan@jpl.nasa.gov

Thank you for participating in this learning experience.

GRS